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LABORATORY EVALUATION OF DUST AND DUST LEAD RECOVERIES FOR SAMPLERS AND VACUUM CLEANERS

VOLUME I: OBJECTIVES, METHODS, AND RESULTS

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Westat, Inc.	Designed the study and wrote portions of and compiled the Quality Assurance Project Plan for the project. Upon completion of the laboratory and chemical analysis, Westat performed the statistical analysis and wrote portions of the final report. John Rogers was the Work Assignment Manager, responsible for the management of the work and for the statistical analysis. Rick Rinehart provided expertise on the design, interpretation, and review of the study results and wrote sections of the report. Brian Dietz was responsible for the preparation of the data files and review of the statistical procedures and statistical sections of the report.
Midwest Research Institute (MRI)	Conducted the laboratory sampling and chemical analysis for the pilot study and full study and wrote portions of the Quality Assurance Project Plan and the final report. Paul Gorman was the Project Leader with responsibility for testing, and directing activities of laboratory personnel. Paul Constant had overall management and fiscal responsibility and reviewed all work products. Jack Balsinger and Karin Bauer, under his direction, were responsible for reviewing the data, conducting quality assurance audits, writing sections on the QA results, and reviewing the reports.
EPA	EPA Staff had overall responsibility for this project and played an active role in directing the pilot study and full study. Principal EPA contributors included Ben Lim, Work Assignment Manager, and John Schwemberger, Deputy Work Assignment Manager.

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EXECUTIVE SUMMARY

Introduction

This project to expand the knowledge on household dust testing methods was undertaken by the U.S. Environmental Protection Agency (EPA) as part of a major national effort to address the public health issue of childhood lead poisoning. The effort was given impetus by the CDC's statement on lead poisoning, which reduced the level of concern for blood lead levels from 25 micrograms/ deciliter (µg/ dl) to 10 µg/ dl. It has also been given impetus by the passage of the "Residential Lead-Based Paint Hazard Reduction Act of 1992," also known as "Title X." In response to Title X, EPA is proceeding towards the development of health-based standards for house dust lead levels. To do this, appropriate methods for sampling house dust are needed. As part of this effort, numerous questions about house dust sampling have risen. This study was designed to address some of these questions.

This project was undertaken by the EPA Office of Pollution Prevention and Toxics (OPPT) to evaluate house dust sampling methods and to assess the efficacy of typical household vacuuming on removing leaded dust from residential surfaces. Dust-lead sampling results from the National Survey of Lead-Based Paint in Housing (HUD National Survey) are reexamined, based on new information collected in this study about the performance of the dust sampler used during that survey.

Lead-contaminated house dust is considered one of the most significant sources of childhood lead exposure in the United States. Millions of children live in dwellings with hazardous dust-lead levels and routinely put dust-laden fingers, toys, and other objects into their mouths. Although the potential hazards of house dust are well recognized, it is currently unknown which dust sampling procedures and methods are best for assessing residential lead hazards. It is also unknown how effectively typical vacuuming lowers dust lead levels in the home.

The primary reason for the lack of scientific consensus on the best method to sample house dust is that several recent studies, including this one, have shown that different samplers give different results under the same circumstances. For example, studies have shown that the amount of dust picked up by one sampling method may be either considerably greater or considerably less than that dust picked up by a second method. Therefore, any conclusions about the level of lead hazard posed by dust may differ depending on the sampling method used. The situation is further complicated by the fact that the previous studies designed to evaluate the performance of house dust samplers are not directly comparable. Since interpretable house dust lead measurements are needed by the Federal government to draft guidelines to address lead hazards in housing, a standardized laboratory procedure to characterize samplers was needed. Such a procedure was developed for use in this study.

The test procedures developed for this study proved easy to implement. It is recommended that they be duplicated by other researchers testing the performance of house dust collection devices. By using the same standardized test procedures, a baseline can be established for samplers and vacuum cleaners and the results from future evaluation studies can then be compared to the baseline. In this way, information from many studies can be combined to make the most appropriate decisions on how to address lead hazards in housing.

Two standardized laboratory testing procedures were developed for this study. The first procedure was designed to characterize the performance of house dust samplers. The second was designed to evaluate how well commercially available vacuum cleaners collect dust from various surface types. Three vacuum sampling methods and one wipe sampling method were tested by the first procedure. These methods included the "Farfel modified" High Volume Small Surface Sampler used in the Baltimore Repair and Maintenance study (called the BRM sampler is this report), the Comprehensive Abatement Performance Study (CAPS) cyclone sampler, the Blue Nozzle sampler, and the Department of Housing and Urban Development's (HUD) wipe sampling method. All of these sampling methods have been used in previous EPA/ OPPT studies. The second procedure was used to characterize four commercially available household vacuum cleaners ranging in price from $120 to $800. The most expensive vacuum cleaner was equipped with a high efficiency particulate air (HEPA) filter. The protocols for both testing procedures included using real house dust sieved into six particle size classes ranging from 0 to 2,000 microns in size. The dust was applied to five substrates commonly encountered inside a residence: tile, wood flooring, linoleum (sheet vinyl), upholstery, and carpet.

Results and Conclusions

Test Dust Characteristics: The test dust used in this study was obtained from volunteers who donated full vacuum cleaner bags of house dust. Bags were collected from homes within two age groups: older homes built before 1963 when lead paint was common and newer homes built after 1982, several years after lead was banned from household paint. As expected, the dust from older dwellings had a higher lead concentration than the dust from newer homes, with mean lead concentrations of 474 parts per million (ppm) and 61 ppm, respectively, for all dust particles smaller than 2,000 microns. The two groups of house dust contained roughly the same proportions of total dust, by weight, in each particle size class. However, the distribution of lead concentration by particle size class was dramatically different between the two age groups. This result was unexpected and has not been demonstrated in previous studies.

Most studies that have examined lead in house dust by particle size suggest that lead concentrations in dust increase as particle size decreases. In this study, the lead concentration in dust collected from newer homes follows the expected inverse

relationship with particle size, but the lead concentrations in dust from the older homes did not exhibit the same relationship. Lead concentrations in the dust collected from pre-1963 homes remained relatively stable across particle sizes. One possible explanation for this observation is that house dust from pre-1963 homes likely contains some deteriorated lead-based paint, while dust from newer homes does not. If deteriorated paint dust particles are larger and more variable in size than other lead sources, such as soil or street dust, then the inverse relationship between lead and particle size may disappear in the dust contaminated by deteriorated lead-based paint.

Samplers: The performances of one wipe sampling method and three vacuum sampling methods were evaluated in this study. The vacuum samplers were tested for total dust recovery (total dust cannot be measured by wipes) and all four samplers were tested for lead recovery. Recovery is the amount of dust or lead collected from the substrate as a percentage of the amount deposited on the substrate. Tests were differentiated by substrate, by the nominal lead concentration of the dust applied to the substrate (high and low lead concentration dust from older and newer homes, respectively), by the dust loading levels (100 and 400 mg/ sq ft.), and by the dust particle size.

The results indicate that the BRM and the CAPS cyclone produced the highest dust recoveries across all substrates and particle sizes. The recovery differences between the two cyclone devices were not significant. The Blue Nozzle sampler had the lowest recoveries, which were statistically significantly lower than for the cyclone samplers. These results agree with findings from previous studies that indicate that the Blue Nozzle sampler has lower dust recovery than other tested methods. The average dust recoveries for the BRM, CAPS, and Blue Nozzle samplers were 89%, 84%, and 30%, respectively. The results also suggest that the measurements from BRM and CAPS cyclone samplers are more precise than those from the Blue Nozzle sampler.

The pattern of lead recovery across samplers was similar to dust recovery. In order of decreasing lead recovery, the lead recoveries of the BRM, CAPS cyclone, wipe, and Blue Nozzle samplers are 81%, 72%, 63%, and 26%, respectively. The lead recovery for the BRM, CAPS, and wipe sampler are all significantly greater than for the Blue Nozzle sampler. Differences in the recovery among different substrates were not statistically significant.

The best methods for measuring lead in house dust depend on many factors, two of which are dust particle size and substrate. It is clear from this study and others that the selection of the sampling method is a critical factor. The differences among samplers have particular application to the interpretation of health-based standards and on the results from the HUD National Survey which are discussed below.

Commercial Vacuum Cleaners: Commercially available vacuum cleaners with beater bar attachments for carpets were tested for total dust and lead pickup capabilities. The

same test dust and substrates used for the samplers were also used for the vacuum cleaners. For the vacuum cleaner tests, the dust loading in mg/ sq ft was the same as for samplers, but the size of the test area was larger so the amount of dust applied was greater than for the sampler tests.

The overall ability of the vacuum cleaners to collect dust was, as expected, greatest for the hard substrates and poorest for carpets. The average dust recovery ranged from 76% on carpets with ground-in dust to 93% on wood substrates. The average recovery for a particular substrate also varied among vacuum cleaners.

While it was simple to weigh the total dust collected in vacuum cleaner bags and thus measure dust recovery, measurement of lead recovery proved difficult because it was not possible to remove all of the dust from the vacuum cleaner bag for lead analysis. It also was not feasible to measure the lead in the dust without removing the dust from the bag. Based on the procedure developed for this study, which analyzed only the portion of dust that could be shaken out of the bag, the overall average lead recovery was 103%. The lead recoveries varied greatly and depended on the combination of vacuum cleaner and substrate used in each test.

The vacuum cleaner tests also assessed the effect of vacuuming effort on dust recovery. On all substrates, most of the dust applied to the substrate was recovered within the first 40 seconds of vacuuming (over an area of 6.8 square feet). Although additional vacuuming collected more dust, the effect of that effort was significant only for carpets with ground-in dust.

The results of this study show that a highly rated vacuum cleaner with a beater bar attachment will pick up at least three-quarters of the loose dust present on a variety of surfaces within a moderate vacuuming time. The amount of additional dust picked up depends on many factors, such as the vacuum cleaner design and whether or not the dust is ground into the surface. The study suggests that lead recovery is similar to the dust recovery. Because this is a laboratory study, no information is available on how quickly dust accumulates in the home or whether acceptable levels of dust lead can be maintained with regular vacuuming. It is clear that vacuuming removes dust and leaded dust from the vacuumed surfaces, thereby reducing the total amount of lead which might pose a risk to young children. It is also clear from previous studies that lower lead loadings are correlated with lower blood lead levels in children. Even though vacuuming removes leaded dust which might be ingested by a child, however, we cannot definitely say that routine vacuuming will reduce leaded dust in a way that will result in reduced blood lead levels.

Tests were also conducted on the exhaust from the vacuum cleaners. The results showed that 0.02% or less of the dust sucked into the vacuum cleaner hose passed through the vacuum cleaner bag. The smallest dust particle size (<53 μm) was used to represent a worst case situation. The exhaust from the vacuum cleaner equipped with the HEPA filter had lower dust concentration than the ambient air. Although these

results indicate that very little of the dust passed through the vacuum cleaner bag in the four tested vacuum cleaners, more research is required to determine whether this result can be extended to other models and old vacuum cleaners found in many homes.

Effect of Sampling Method on Estimates from the HUD National Survey of Lead-Based Paint: The Blue Nozzle sampling method was used in the HUD National Survey of Lead-Based Paint to estimate the number of priority homes in the U.S. with children under seven years old. Priority homes are classified as private dwelling units containing lead-based paint, with either non-intact paint present or dust loading levels exceeding the HUD post-abatement clearance guidelines. Based on the relative recoveries of the different samplers tested in this study, the number of priority homes which would have been identified if the wipe sampling method had been used in the HUD National Survey was calculated. HUD recommends that wipe sampling be used for post-abatement clearance testing.

The number of priority homes with children under seven was reported as 3.8 million in the 1990 HUD Comprehensive and Workable Plan to Congress. This number was later revised to 4.0 million after new information was included on the performance of the x-ray fluorescence (XRF) instruments used to detect the presence of lead-based paint. Based on the results of this study, the number of priority homes with children under seven would be 4.6 million if wipe sampling techniques had been used during the HUD National Survey.

Additional Questions

Some of the issues and questions raised by this study which have yet to be answered include the following:

- In dust from older homes, the lead concentration was found to be similar for all dust particle sizes except the largest size which had a higher lead concentration. This relationship was based on dust composited from vacuum cleaner bags from seventeen homes. Additional studies of dust collected from individual homes may provide information on the extent to which this relationship can be generalized to all older homes.

- If it is determined that vacuuming can reduce the lead hazard from floor dust without increasing the hazard from other sources, another question to answer is: what vacuuming frequency is necessary to adequately control dust and lead loading?

- For the vacuum cleaners, roughly 2% to 5% of the dust deposited on the substrate was not accounted for. This dust may have been caught in parts of the vacuum cleaner other than the bag, become airborne, been deposited on surfaces other than the vacuumed area, or been caught in

the substrate so as not to be removable with extensive vacuuming. Where is this dust and might it pose a threat to children?

- The extent to which the vacuum cleaner and its exhaust disturb dust, making it airborne and creating a temporary lead hazard, has yet to be determined. How much dust is kicked up by routine vacuuming? Is it hazardous to young children? How soon does the airborne dust resettle, and how soon after vacuuming are airborne dust and lead levels safe for children? Does the vacuuming and/or exhaust cause the uncollected dust to move to areas which provide an increased or decreased lead risk to children?

These questions provide direction for future research.

1 INTRODUCTION

This project to expand the knowledge on household dust testing methods has been undertaken by the U.S. Environmental Protection Agency (EPA) as part of a major national effort to address the Public Health issue of lead poisoning. The EPA, the U.S. Department of Housing and Urban Development (HUD), the Centers for Disease Control (CDC), the Occupational Safety and Health Administration (OSHA), and numerous other Federal, state, municipal, county, industry, and private agencies have been mobilized in an effort to reduce the preventable occurrence of lead poisoning, particularly in children. This effort has been given impetus by both the CDC's statement on lead poisoning, which reduced the level of concern for blood lead levels from 25 micrograms/ deciliter (µg/ dl) to 10 µg/ dl, and by the passage of the "Residential Lead-Based Paint Hazard Reduction Act of 1992," also known as "Title X."

The EPA is currently developing health-based standards for house dust lead levels and approving methods for sampling house dust. As part of this work, numerous questions about the sampling of house dust have arisen. Three important questions are:

1. What are the best methods of measuring lead in house dust?

2. What levels of dust lead can be maintained by a typical homeowner using regular vacuuming?

3. Can a homeowner be assured that the vacuuming process does not create an airborne lead hazard? Or, stated another way, how much leaded dust passes through household vacuum cleaner bags under normal use?

These important questions lead to the following more specific questions:

4. How do different scientific field sampling devices perform under various field conditions?

5. What factors affect household vacuum cleaner performance?

6. Do household vacuum cleaners perform about the same in the laboratory as they do in the home?

7. How fast does dust accumulate in the home?

8. How effective is regular cleaning in the home?

This study addresses aspects of the these questions through a series of laboratory experiments. The results of this study, other studies, and future field work should, when combined, provide answers to these questions.

1.1 Purpose of the Project

Lead-contaminated house dust is considered one of the most significant sources of childhood lead poisoning in the United States. Until recently, little was known about the public health significance of house dust. Furthermore, little was known about how to measure dust-lead levels in the home, how to relate sampling results to actual health risks, or how to safely clean dust from residential surfaces. While the significance of house dust is still not fully understood, recent advancements in our state of knowledge have been made by the EPA, other government researchers, and the private sector. These advancements include an increased understanding of house dust characteristics, the realization that different samplers give different results under the same circumstances, that different commercial household vacuum cleaners are not equal in their dust-pickup capabilities, and that previous studies designed to evaluate the performance of samplers or vacuum cleaners are not necessarily comparable. Interpretable house dust lead measurements and safe, reliable dust-cleanup methods are needed for the Federal government to draft guidelines to address lead hazards in housing, to develop a standardized approach to characterize house dust samplers, and to evaluate vacuum cleaners. These are important objectives of the current study.

During a previous research study, the Comprehensive Abatement Performance Study (CAPS), conducted by the EPA's Office of Pollution Prevention and Toxics (OPPT), differences in results between wiped and vacuumed samples of house dust were noted. Because of these differences, EPA was concerned over making policy decisions based solely on dust sampling results. The purpose of the current task is to answer some of the questions that have been raised concerning sampling house dust. Of special concern is the vacuum sampling method used in the National Survey of Lead-Based Paint in Housing (also known as the HUD National Survey) and the resulting lead levels measured in the dust.

This project characterizes the performance of three vacuum and one wipe sampling method used in previous OPPT studies. The characterization was accomplished by measuring the recovery of the vacuums and wipes using several different particle sizes of dust. The project results should improve interpretations and comparisons across studies that used different means for collecting household dust.

The project also initiated research on the collection of dust and lead dust particles by household vacuum cleaners available to homeowners and renters. It is anticipated that, as residential lead hazards become even more widely publicized, homeowners and renters will rely on vacuum cleaners to minimize the lead dust hazard in their homes. The main purpose of this study is to identify factors which are important in determining the dust and lead pickup efficiency of household vacuum cleaners including collecting data to evaluate how well several commercially available vacuum cleaners collect different size dust particles from different surface types.

A secondary purpose is to assess the amount of dust exhausted into the air while dust is being vacuumed. The Federal government has concerns that routine vacuuming of

highly lead-contaminated dust may create unseen health hazards by polluting the air with lead particles. Lead abatement specialists use vacuum cleaners equipped with a special high efficiency particulate air (HEPA) filter to clean up lead-contaminated dust. The HEPA filters prevent fine lead particles from escaping the vacuum cleaner through the exhaust and, thus, prevent a potential airborne lead hazard. While vacuum cleaners fitted with HEPA filters are available, they usually are expensive and not readily accessible to the general public, although the situation is improving. This project measured the recovery and exhaust emissions of lead dust in a laboratory setting by four different vacuum cleaners currently available for household use. One of these vacuum cleaners was equipped with a HEPA filter.

1.2 Overview of the Report

The rest of this report is devoted to the presentation of background information, study objectives, and methods and results. The report is divided into two volumes. Volume I presents the background, methods, and study results. For readers interested in the specific sampling and analysis procedures, or those interested in replicating the procedures, Volume II contains the appendices from the Quality Assurance Project Plan (QAPjP) which describe the sampling and analysis procedures. The following list provides a brief description of the contents of each section in this report.

Volume I: Objectives, Methods, and Results

Section 1 — Provides a basic introduction to current issues in the sampling of dust and dust lead and an overview of the report.

Section 2 — Reviews background material and related studies on the house dust sampling methods selected for this study.

Section 3 — Describes the objectives for the laboratory evaluation of dust and dust lead recoveries for samplers and vacuum cleaners, including the data quality objectives.

Section 4 — Presents the study design and sample collection procedures (specific protocols are in Volume II).

Section 5 — Summarizes the laboratory analysis procedures (specific protocols are in Volume II).

Section 6 — Presents the results of the study as they relate to the objectives presented in Section 3.1.

Section 7	Discusses the study results in light of the unanswered questions about dust sampling, including a discussion of possible adjustments to the results from the HUD National Survey.
Section 8	Discusses the details of the data analysis, including data entry, data processing, and statistical analysis procedures and measurement precision.
Section 9	Describes the quality assurance aspects of the study, including the system audit, performance audits, data audit, and data assessment.
Appendix A	Presents the analysis and results from the Pilot Study.
Appendix B	Presents and summarizes the preconditioning data.
Appendix C	Lists the sieved dust test data from this study.
Appendix D	Lists the sampler test data from this study.
Appendix E	Lists the vacuum cleaner test data from this study.

2 BACKGROUND

The purpose of this section is to provide background information that will help the reader to understand the objectives of the study. Important concepts that recur throughout the document are explained below. Section 2.1 provides an overview of house dust and the importance of dust particle size. Section 2.2 introduces the sampling methods evaluated in this study and gives a brief history of the use of these sampling methods in previous OPPT studies. Vacuum cleaners that are available to the public are also discussed. Finally, Section 2.3 reviews previous sampling method comparison studies, both in the laboratory and in the field.

2.1 Importance of House Dust Particle Size

House dust is a complex mixture of particles and fibers that accumulates on residential surfaces. All house dust contains lead particles. The amount depends on the extent of lead contamination from sources such as soil tracked into the residence or deteriorated lead-based paint. A significant portion of dust consists of fine particles, which may be the most biologically important fraction of the dust. Fine dust particles stick to a child's hands more readily than do larger dust particles and it is hypothesized that they are more likely to be swallowed during normal hand-to-mouth activity.[1,2,3] However, this has not been demonstrated by empirical evidence nor has it been extensively studied.

Fine dust has further biological importance in that lead absorption into the body via the gastrointestinal tract is inversely related to particle size.[4] The smaller the lead particle, the more efficiently it is absorbed into the body. Although it is not known if children are exposed primarily to fine dust particles, because fine particles adhere to the skin more readily than coarse particles, house dust sampling and cleaning regimes that are efficient in removing fine particles may be the most efficacious.

The efficiency with which dust is collected from a surface during sampling or cleanup may depend on particle size. Thus, it may be important to know how well a particular sampler or vacuum cleaner collects various sizes of dust particles in order to evaluate its performance. As mentioned in Section 1, the current study is designed to evaluate the dust and lead pickup efficiencies for samplers and vacuum cleaners using different particle sizes. The purpose is to create a reproducible baseline of performance

[1]Que Hee, S.S., Peace, B., Clark, C.S., Boyle, J.R., Bornshein, R.L., and Hammond, P.B.: Evolution of Efficient Methods to Sample Lead Sources, Such as House Dust and Hand Dust, in the Homes of Children. Environmental Research. 38: 77-95 (1985).
[2]Duggan, M.J., Inskip, M.J., Rundle, S.A., and Moorcroft, J.S.: Lead in Playground Dust and on the Hands of School Children. The Science of the Total Environment. 44: 66-79 (1985).
[3]Driver, J.H., Konz, J.J., and Whitmyre, G.K.: Soil Adherence to Human Skin. Bulletin of Environmental Contamination Toxicology 43: 814-820 (1989).
[4]Barltrop, D. and Meek, F.: Effect of Particle Size on the Lead Absorption. From the Gutmann Archives of Environmental Health. 280-285 (July/August, 1979).

characteristics, by particle size, to compare how well different collection methods remove a wide range of particle sizes from surfaces.

2.2 House Dust Sampling and Collection Methods

Two fundamentally different types of dust sampling methods, wipe and the vacuum methods, are available to sample house dust. Researchers have developed more than 15 variations of the two methods. When used side by side, the different variations typically give different results. This makes it difficult for the Federal government to project national estimates or to develop health-based standards for lead in house dust, since the lead level measured by a single dust sample is affected by the sampling method employed. It is therefore important to understand how different sampling techniques compare with each other before the results from different studies can be interpreted.

When comparing the dust sampling methods, it is important to understand the relationship among lead concentration, total dust, and lead loading. Lead concentration is a measure of the proportion or fraction of the dust which is lead, on a weight basis. Total dust refers to the amount of dust on the surface. When these two measures are multiplied together, the product is lead loading, the amount of lead on the surface.

Lead loading is expressed by the Federal government as micrograms of lead per square foot of surface (µg/ ft^2). Lead Concentration (µg/ g) x Total Dust (g/ ft^2) = Lead Loading (µg/ ft^2). Common wipe sampling techniques measure lead loading. The total dust weight collected on the wipe is very small compared to the total weight of the wipe material itself. Therefore, wipe sampling cannot measure lead concentration because there is no way to accurately weigh the total dust collected from the sampled surface. The only way to measure dust-lead concentration is to use a vacuum sampling technique. Most vacuum samplers collect the dust sample in a way that allows a quantitative weight measure of the dust collected from the surface, thus allowing analysis of the lead concentration in the collected dust.

2.2.1 Wipe and Vacuum Sampling Methods Used in this Study

The 1990 HUD Interim Guidelines for Public and Indian Housing describe the HUD wipe sampling method used in this study. It is the most commonly used residential wipe sampling method in the United States. This technique uses premoistened baby towelettes and is designed for hard, relatively smooth surfaces.

The three vacuum sampling methods used in this study were the Blue Nozzle, the CAPS cyclone, and the BRM. The Blue Nozzle method was developed in 1989 by MRI for the HUD-sponsored National Survey of Lead-Based Paint in Housing. This method was developed because other methods available at the time were not sufficient for the requirements of the HUD National Survey. Namely, a vacuuming method was needed

that could measure both lead concentration and loading and allow sampling areas to be covered in only a few passes to reduce sampling time. The Blue Nozzle sampler consists of a laboratory rotary vane pump connected to a 0.8 µm mixed-cellulose ester membrane filter cassette via thick-walled 3/ 8" Tygon tubing. The cassette is used open faced and a specially designed angle-cut Teflon nozzle, 4" long x 2" wide, fits over the cassette with O-rings to seal it. The Blue Nozzle name was coined for the color of the nozzle.

In 1991, MRI developed the CAPS cyclone, a portable, AC-powered particle separator sampler (similar to a cyclone) from standard PVC pipe and pipe fittings and a commercially available hand-held vacuum. It was designed to be an inexpensive vacuum sampler made from materials commonly found in hardware stores. This sampler was characterized by the MRI Engineering Study to Explore Improvements in Vacuum Dust Collection and used in the EPA Comprehensive Abatement Performance Study (CAPS), both described below.

Shortly thereafter, Farfel at Baltimore's Kennedy Krieger Institute modified a cyclone house dust sampler originally developed for EPA's Office of Research and Development (ORD) in Research Triangle Park, North Carolina. Farfel used the same cyclone developed for ORD, called the HVS3 cyclone, but used the portable hand-held vacuum that MRI used for the CAPS cyclone, instead of the less-portable upright vacuum used by ORD. Rigid PVC and, after further modifications, flexible tubing was attached to the cyclone to allow small areas to be vacuumed. This sampler was developed for the EPA Lead-Based Paint Abatement Repair and Maintenance Study (R&M Study) conducted in Baltimore, discussed below, and is referred to as the BRM sampler.

2.2.2 History of Dust Sampling Methods Used by OPPT

The Office of Pollution Prevention and Toxics (OPPT) has considerable experience collecting house dust to measure residential lead levels. Some of the current popular methods were used during, or first developed for, OPPT research studies. This section gives a brief history of the use in previous OPPT studies of the samplers tested in the current study.

The EPA, OPPT worked collaboratively with HUD during the HUD National Survey of Lead-Based Paint conducted in 1989-1990. The purpose of HUD's national survey was to better estimate the extent of lead paint hazards in the nation's housing stock. House dust was collected in hundreds of homes, nationwide, with the Blue Nozzle method developed specifically for this study. The Blue Nozzle sampler was also used in the EPA, OPPT R&M pilot study, which was conducted in six Baltimore dwellings. Currently the BRM sampler is being used in the full EPA R&M study.

The EPA, OPPT Comprehensive Abatement Performance Pilot Study (CAPPS) was designed in part to assess the performance of sampling and analysis methods and to

compare the Blue Nozzle with the HUD wipe sampling protocol planned for the full Comprehensive Abatement Performance Study (CAPS). Because the CAPPS study showed that the Blue Nozzle method performed poorly compared to the wipe sampling, EPA contracted with MRI to conduct an engineering study to explore improvements in vacuum dust collection. During this study, MRI developed the CAPS cyclone for use in the CAPS study. The HUD wipe method was used during both the CAPS study and CAPPS study.

2.2.3 Commercial Vacuum Cleaners

As mentioned in Section 1, the main purpose of the vacuum cleaner element of this study is to evaluate how well several commercially available vacuum cleaners collect different size dust particles from different surface types. A secondary purpose is to assess the amount of dust exhausted into the air while dust is being vacuumed. Four commercially available vacuum cleaners with beater bar attachments (i.e., "power nozzles") were selected for testing, ranging in price from $120 to $800. Each tested vacuum cleaner is described below. They are not identified by the manufacturer's name, but by the letters A, B, C, or D.

Vacuum cleaners A, B, and C are canister-type vacuums and D is an upright vacuum. Vacuum cleaner A is a top-of-the-line non-HEPA canister vacuum cleaner ($400) and is widely available. Vacuum cleaner B is a lower-cost canister vacuum that cost $300. Vacuum cleaner C is the only household vacuum tested in the current study that is equipped with a HEPA filter. It represents a relatively expensive vacuum ($800) and is new on the market. Finally, vacuum cleaner D is a popular upright vacuum with a price of $120.

2.3 Previous Studies that Compared Samplers and Vacuum Cleaners in the Laboratory and Field

Sampling method and vacuum cleaner characterization studies are important to assess both the dust-pickup performance on different surfaces and how the performance differs among devices. The following studies show the variety of procedures used to test sampling methods. The test methods described in the next sections are well designed, but they differ significantly. Researchers do not yet agree on the best reference materials to characterize dust sampling methods. The procedures designed for the current study were developed after careful review of the previous work done in this area. The aim was to develop standard reference materials to be used on standardized surfaces in a standardized manner to facilitate comparability between studies in the future.

2.3.1 Laboratory Comparison Studies: Real versus Artificial House Dust

Several researchers have characterized house dust sampling systems in the laboratory with artificial house dust made from sand, soil, talc, corn starch, and paint chips. The advantages of creating a well-defined artificial dust include the ability to control outside variability in experiments and to obtain good measures of the relative differences between sampling techniques on the substrates on which the dust is placed. However, the downside of these experiments is that artificial house dust may not represent dust found in homes. Dust found in homes is oily and sticky and has other characteristics that cannot be duplicated with artificial dust. Unfortunately, house dust must be collected first in the home to be used as a test dust. This initial collection process may bias the dust particle size distribution toward particles that are more easily collected. Thus, laboratory tests performed with these dusts may overestimate the sampler's capability in the field. However, although using dust collected from homes may introduce some limitations in interpreting the results from laboratory performance tests, the limitations imposed by using artificial dust were deemed to be much greater. For this reason, house dust was used in the current study.

One of the first and frequently cited laboratory comparison studies was conducted by Que Hee et al. (1985). He collected house dust in several houses with vacuum cleaners containing standard vacuum cleaner bags. The portion of the dust from these bags that passed through a 149 µm sieve was retained as loose test house dust and was used to determine sampling collection efficiency of a dust sampling method Que Hee designed. Dust weights of 10, 20, 30, 40, 50, and 100 mg were placed as evenly as possible on different surfaces and vacuumed up to measure the overall collection efficiency of the sampler. Further tests were conducted with other house dust sieved into the following six particle size classes: <44, 44-149, 149-177, 177-246, 246-392, and 392-833 µm. These additional tests determined the sampler collection efficiency for different particle size classes on a variety of surfaces.

The EPA, ORD (1989)[5] evaluated the High Volume Surface Sampler (HVS2, predecessor of the HVS3) sampler for its own use using a modified American Society of Testing and Materials (ASTM) Method F608-79 (1987, developed by the Hoover Company, North Canton, Ohio for household vacuum cleaners). The ASTM method called for an artificial test dust of 90 percent sand and 10 percent talc spread on and embedded into a test carpet by dragging a large, smooth weight across the surface. The EPA modified the test dust to better match the reported composition of house dusts. The new mixture was 45 percent sand, 45 percent talc, 9.5 percent food-grade cornstarch, and 0.5 percent technical-grade graphite. The cornstarch and graphite particles were found to be more than 99 percent less than 75 µm, while the particle size of the test sand was:

[5]United States Environmental Protection Agency. Project Summary: Development of a High Volume Surface Sampler for Pesticides in Floor Dust. by J.W. Roberts and M.G. Ruby. EPA/ 600/ s4-88/ 036. January 1989

20 percent >300 µm
70 percent between 300 and 150 µm
2 percent between 150 and 106 µm
7 percent between 106 and 75 µm, and
1 percent < 75 µm.

On a subsequent sampling system, Research Triangle Institute (1990) modified the artificial dust to consist of 10 percent talc and 90 percent fine sand (<150 µm). The same sampler was retested by Roberts et al. (1991) with "real" house dust collected from carpets in six houses with an upright Hoover convertible vacuum cleaner with an beater bar. The collected dust was removed from the vacuum cleaner bags, mixed, and sieved to <150 µm, similar to Que Hee's approach. Approximately 15.9 g/ m^2 of the dust was added to carpets using the ASTM method, and sampler collection efficiency was then determined.

The EPA, OPPT-sponsored MRI Engineering Study to Explore Improvements in Vacuum Dust Collection, mentioned previously, was designed to test samplers using artificial dust. Three different particle size classes were prepared in the laboratory: < 250 µm, 250 µm to 2,000 µm, and > 2,000 µm. The artificial dust consisted of dirt, sand, and paint chips and was applied to a surface by hand as evenly as possible over the one-foot square inscribed area of the surface. Each sampling test consisted of vacuuming a one-square foot area on wood floor, linoleum, concrete, carpet, or a window sill. Dust was not ground into the carpets. The authors' interpretation of the results showed the Blue Nozzle to be the least efficient sampler for dust sampling. The CAPS cyclone sampler achieved the best results.

Farfel (1993) used artificial dusts to characterize various house dust samplers, including the Blue Nozzle, the CAPS cyclone, and the BRM. Three different dusts were used: (1) a "large-diameter" dust (250-2,000 µm) made from dried sand and soil; (2) an "intermediate diameter" dust (38-149 µm) made from NIST Standard Reference Material #2704 (a soil standard); and (3) a "small diameter" dust (<44 µm) made from talc. Farfel's data showed that the BRM exhibited less bias across all of the particle size classes than the other samplers.

Lioy et al. (1993)[6] used two types of dust to characterize a wipe sampling device: Arizona road dust with particle sizes less than 80 µm (39%, < 5 µm; 18%, 5-10 µm; 16%, 10-20 µm; 18%, 20-40 µm; 9%, 40-80 µm) and an all-purpose potting soil, composed of organics and sand, which was dried and sieved to provide a particle size of less than 75 µm. The authors state that the sieving removed a large percentage of the sand. They used a deposition chamber to load the test dust uniformly onto different surface types. Actual house dust was not used in the resuspension experiments because hair and

[6]Lioy, P.J., Wainman, T., and Weisel, C.: A Wipe Sampler for the Quantitative Measurement of Dust on Smooth Surfaces: Laboratory Performance Studies. Journal of Exposure Analysis and Environmental Epidemiology. 3(3): 315-330 (1993).

other materials would clog the generator and inhibit uniform deposition in the chamber.

2.3.2 Laboratory Comparison Studies: Test Surfaces and Collection Efficiency

The test surface is related to efficiency of dust collection. The type of surface sampled directly affects the amount of total dust collected from the surface. Furthermore, different sampling techniques collect different amounts of dust from a surface that has the same dust loading. The difference is due to different *collection efficiencies* of the samplers. When evaluating devices, it is important to use several different test surfaces to fully characterize and compare the samplers. If meaningful comparisons among studies are desired, the same types of surfaces must be used by different researchers conducting separate laboratory comparison studies.

2.3.3 Field Comparison Studies

Field comparison studies are important because they bring an element of reality that cannot be duplicated in the laboratory. While it is not possible to obtain "true" dust collection efficiencies in the field, it is possible to measure relative collection efficiencies between sampling devices using side-by-side samples. It is important to follow up on findings observed in the laboratory to determine if they hold up in the "real world." The EPA, OPPT has conducted several field sampling method comparison studies, which were briefly described in Section 2.2. They are discussed in more detail below. A recent field comparison study conducted by the National Center for Lead-Safe Housing (NCLSH) is also presented.

The EPA, OPPT R&M pilot study collected side-by-side wipe and vacuum dust samples. The results showed that side-by-side wipe and vacuum floor dust samples were highly correlated ($r=0.84$; $p < 0.001$; $n=68$). However, findings also revealed that wipe lead loadings were 3.4 to 5.6 times higher than those observed by the Blue Nozzle method.

The EPA, OPPT Comprehensive Abatement Performance Pilot Study (CAPPS) collected two side-by-side floor samples using the Blue Nozzle vacuum and the HUD wipe sampling method. The wipe sampling procedures showed lead loadings ($\mu g/ ft^2$) for floor samples to be approximately 10 times higher, and lead loadings for window stool samples to be approximately 5 times higher, than samples collected by the Blue Nozzle method. For the EPA, OPPT Comprehensive Abatement Performance Study (CAPS), side-by-side vacuum/ wipe samples were not statistically different. Unlike the pilot study, the CAPS study used the CAPS cyclone sampler. The estimate of vacuum/ wipe ratio was 1.42 with a confidence interval of 0.78 to 2.60. The difference between the two methods appeared to increase with the roughness of the substrate. It was also found

that, on the average, side-by-side vacuum measures were significantly more variable than side-by-side wipe measures.

The NCLSH recently funded two studies: (1) a pilot study to field test five different sampling methods, side by side and (2) a correlational study to assess the relationships between settled lead dust and blood lead levels in children, using three methods chosen from the first study. The first study was conducted by the University of Cincinnati. The sampling methods used included the University of Cincinnati method (a vacuum sampler made from common industrial hygiene sampling materials), Farfel's BRM sampler, the HUD wipe method, Farfel's wipe method, and the LWW wipe sampling method (a specially designed wipe sampling device, capable of reporting both lead loading and concentration). Cincinnati collected five side-by-side samples in 20 homes, in three rooms per home and two samples per room.

The second NCLSH study includes quantifying the relationships among a wide range of settled dust levels and blood lead levels. Methods include using side-by-side vacuum and wipe sampling on floors, window sills, and window wells in a minimum of three rooms per dwelling unit, including the child's bedroom and the principal play area. The results for both studies are pending.

3 STUDY OBJECTIVES

Many measures exist to determine the effectiveness of dust removal methods. One such measure is "recovery" or the percentage of dust collected from a surface by weight. Characteristics of dust and surface that may affect recovery include the size and source of the dust particles, the type of surface on which the dust lies, and whether it is ground into the surface. Characteristics of dust removal devices that affect recovery include the amount of suction (or face velocity), the efficiency at capturing dust particles, and the type of "head" that contacts the surface. The objectives of this study are to examine the ability of several dust removal devices to recover both dust and lead from five preselected surfaces under a variety of conditions.

3.1 Questions to be Answered with the Data

This study focuses on two types of dust removal devices as discussed in the previous sections: scientific field sampling devices and household vacuum cleaners. Throughout this document, the term "sampler" refers to a device that is appropriate for measuring dust and lead levels over small areas for scientific purposes. The four sampling methods tested in this study are specifically designed for this purpose. The term "vacuum cleaner" refers to a consumer product designed to vacuum in the home. The following six study objectives are concerned with examining the differences between and within these two types of dust removal devices.

(1) For household dust collected in vacuum cleaner bags, estimate the percentage of dust and the lead concentration for various dust particle size classes.

(2) For selected samplers, estimate dust recovery and lead recovery for various substrates and dust particle size classes.

(3) For selected vacuum cleaners, estimate dust recovery and lead recovery for various substrates and dust particle size classes.

(4) For selected vacuum cleaners, estimate how dust recovery and lead recovery change with cleaning effort.

(5) For selected vacuum cleaners, estimate how exhaust dust levels change over time as dust enters a new vacuum cleaner bag.

(6) For all laboratory experiments, estimate sampling and measurement errors.

Section 8 presents the study results that address these specific objectives.

3.1.1 Samplers

Four samplers were used in this study: 1) the HUD wipe sampling method which uses premoistened baby wipes (Wipes); 2) the BRM sampler (Baltimore Repair and Maintenance Study modified HVS3 Cyclone sampler, BRM); 3) the CAPS Cyclone sampler (CAPS); and 4) the Blue Nozzle sampler. These samplers were selected because they were used in prior studies conducted by the EPA.

The objectives for samplers were designed to provide information to answer the following questions:

- For the two fundamental methods of sampling house dust for scientific purposes (wipe and vacuum), which method is more precise and how can the relationship between them be characterized?

- What are the variances attributable to person-to-person differences among sampling technicians and sample-to-sample variation by one technician when taking wipe samples and vacuum samples?

Although not specified in the original objectives, the study was designed to use different substrates and dust in different particle size classes in order to answer the following questions:

- What role does the substrate play in the sampling of dust by both wipes and vacuum samplers?

- Do vacuums and wipes show a preferential or uniform pickup of the various particle size classes of house dust? If there is preferential pickup, what are the recoveries of wipes and vacuums for the different size classes?

Finally, can the study results be used to decide if it is necessary to adjust the HUD National Survey vacuum data and, if so, how might it be adjusted? Section 9 discusses the study results in light of these questions.

3.1.2 Vacuum Cleaners

Four vacuum cleaners were used in this study: 1) an inexpensive canister model (vacuum cleaner A), 2) a highly rated model without a HEPA filter (vacuum cleaner B), 3) a highly rated canister model with a HEPA filter (vacuum cleaner C), and 4) a popular upright model (vacuum cleaner D). These vacuum cleaners were selected because they are commercially available, fairly popular, and/or cover a range of vacuum cleaner characteristics, based on preliminary information. All were equipped with a beater bar attachment.

Collection Efficiency

As mentioned earlier, the vacuum cleaner element of this study was included to evaluate the collection efficiency of the four vacuum cleaners. Two collection efficiency objectives of the vacuum cleaner tests are to estimate the dust recovery and lead recovery for various substrates and dust particle size classes and to estimate how the dust recovery changes with cleaning effort.

Exhaust Tests

Concern has been expressed that small dust particles, possibly those with the greatest lead hazard, will be expelled in vacuum cleaner exhaust, thereby reducing the effectiveness of vacuuming for controlling leaded dust. This is not an issue for vacuum cleaners that have a highly efficient HEPA filter in the exhaust stream, but it may be for those without a HEPA filter. While the experiments performed in the collection efficiency study will provide estimates of overall recovery rates, they will not provide estimates of the amount of exhausted dust. Therefore, a separate experiment was conducted to estimate the amount of dust that is expelled in vacuum cleaner exhaust as dust enters a new vacuum cleaner bag.

3.2 Data Quality Objectives

The primary objectives of this study are to estimate dust and lead recovery for samplers and household vacuum cleaners using dust of different particle sizes. Because the collection of dust bags was based on voluntary procedures rather than a probability sample, no data quality objectives have been established for determining the distribution of dust mass by particle size class. The data quality objectives for the recovery measurements are to estimate:

(1) Overall percent recovery of dust for a vacuum or wipe method across all tests with a 95 percent confidence interval of +/- 8 percent

(2) Average percent dust recovery for a vacuum or wipe method on each substrate with a 95 percent confidence interval of +/- 15 percent

(3) Average percent dust recovery for a vacuum or wipe method on each combination of substrate and particle size class with a 95 percent confidence interval of +/- 30 percent

These data quality objectives were established based on a consideration of what could be achieved with the available resources and what precision was acceptable to EPA. No specific data quality objectives for estimates of lead recovery were established because relevant estimates of precision were not available at the time the study was designed. Since the objective of measuring the exhaust dust levels is to identify relative

changes over time and to determine if the measurements can be made reliably, no data quality objectives have been established for these measurements.

4 STUDY DESIGN AND SAMPLE COLLECTION PROCEDURES

4.1 Study Design

This study required performing laboratory tests on four vacuum cleaners and four samplers to determine their dust and lead (Pb) pickup efficiency (i.e., recovery). The study design included tests of several factors, listed in Table 4-1, on the dust and lead recovery. The tests were performed according to the study design previously discussed in the QAPjP,[7] except for some changes that were made based on information obtained from the pilot study.[8] Some changes were also made in preconditioning substrates, necessitated by difficulties in achieving the desired limits on weight gain in vacuuming carpet and upholstery, as explained later in this section.

Vacuum cleaners A, B, and C are canister model units with all attachments including powered beater bars (i.e., "power nozzles") for use on rugs (see Section 2.2.3). Vacuum cleaner D is an upright model that uses a larger bag for dust collection. For this model, the dust collection bag is on the discharge side of the blower, rather than on the suction side as in the canister models. See Figures 4-1, 4-2, 4-3, and 4-4 for photos of each vacuum cleaner. The attachments shown are those which came with the vacuum cleaner. Only the attachments for floors (with the beater bar) and upholstery were used in the study. When performing the tests, the canister vacuum cleaners were placed on the floor beside the platform with the substrate.

The four samplers used are commonly referred to as baby wipes (wipes), BRM sampler, CAPS sampler, and Blue Nozzle sampler. Photos of each sampler are shown in Figures 4-5, 4-6, 4-7, and 4-8, and each is described in detail in Volume II of this report.

Reference dust used in the tests was obtained from normal household vacuum cleaner bags, as discussed in Section 4.2. There were two groups of dust: high lead dust (dust from older homes built before 1963) and low lead dust (dust from newer homes built after 1982). At the time of the study design, it was assumed that the dust from older homes would have higher lead concentrations than the dust from newer homes. Therefore, the dusts from older and newer homes are said to have high and low *nominal lead concentrations*. Dust in each group was sieved into the six particle size classes (Table 4-1) that were used in the study. Dust of selected particle size classes was applied to substrates using two dust loadings, 100 mg/ft^2 and 400 mg/ft^2.

Since the personnel operating the vacuum cleaners and samplers could influence the results, two different teams were used in carrying out the tests. These are referred to as Team 1 and Team 2; each team performed specific tests as directed in the test sequence provided in this section.

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[7] Quality Assurance Project Plan for the Wipe and Vacuum Study, dated September 24, 1993 (EPA Task Manager Dr. Ben Lim).

[8] See Appendix A for "Pilot Test Results for the Wipe and Vacuum Study."

The procedures for testing dust recovery followed the ASTM F608-89 method to the extent that it was consistent with the objectives of the study. The ASTM method is described in Appendix C of Volume II.

The substrate types for the study were chosen to include a variety of surface characteristics commonly present in homes. The specific examples of each substrate were selected based on usage reported by retailers. The selected substrates were commonly used and available. Figures 4-9 to 4-13 present photos of each of the six different substrates used in this study:

- Vinyl tile
- Carpet
- Carpet with ground-in dust (dust ground in following ASTM procedure)
- Sheet vinyl (or linoleum)
- Wood
- Upholstery

To avoid cross-contamination due to the use of dust with two nominal lead concentrations and the two dust loadings, four separate sections of each of the six substrates were required. Each of the four sections was labeled as follows:

- Low lead, low loading
- High lead, low loading
- Low lead, high loading
- High lead, high loading

Each substrate section measured 72 x 27 in., and the vacuum cleaner test area used within that area was 54 x 18 in. (i.e., 6.75 ft^2) per ASTM F608-89. The test area used for the sampler tests was 12 x 12 in. (i.e., 1.00 ft^2). A 6-in. high platform (72 x 29 in.) was used to support substrates for the tests, as shown in Figure 4-14.

Table 4-1 Factors affecting dust and lead recovery

Factor	Type/levels
VACUUM CLEANERS	
Substrate	Carpet, carpet with grind-in, linoleum, wood, upholstery, vinyl tile
Dust particle size class	<53 μm; 53 to 106 μm; 106 to 150 μm; 150 to 212 μm; 212 to 250 μm; 250 to 2,000 μm
Dust loading	100 mg/ft^2, 400 mg/ft^2
Nominal lead (Pb) concentration	Low, high
Team	1, 2
Vacuum cleaner	Models A, B, C, and D
SAMPLERS	
Substrate	Carpet, carpet with grind-in, linoleum, wood, upholstery
Dust particle size class	<53 μm; 53 to 106 μm; 106 to 150 μm; 150 to 212 μm; 212 to 250 μm; 250 to 2,000 μm
Dust loading	100 mg/ft^2, 400 mg/ft^2
Nominal lead (Pb) concentration	Low, high
Team	1, 2
Sampler	Baby wipes, BRM, CAPS, Blue Nozzle

Figure 4-1 Vacuum cleaner A

Figure 4-2 Vacuum cleaner B

Styrofoam
BRAND
40
THE BEST
PROVEN VALUE
SCORE
BOARD

Figure 4-4 Vacuum cleaner D

Figure 4-5 Wipe sampling

Figure 4-6 Blue Nozzle sampler

Figure 4-7 BRM sampler

Figure 4-8 CAPS sampler

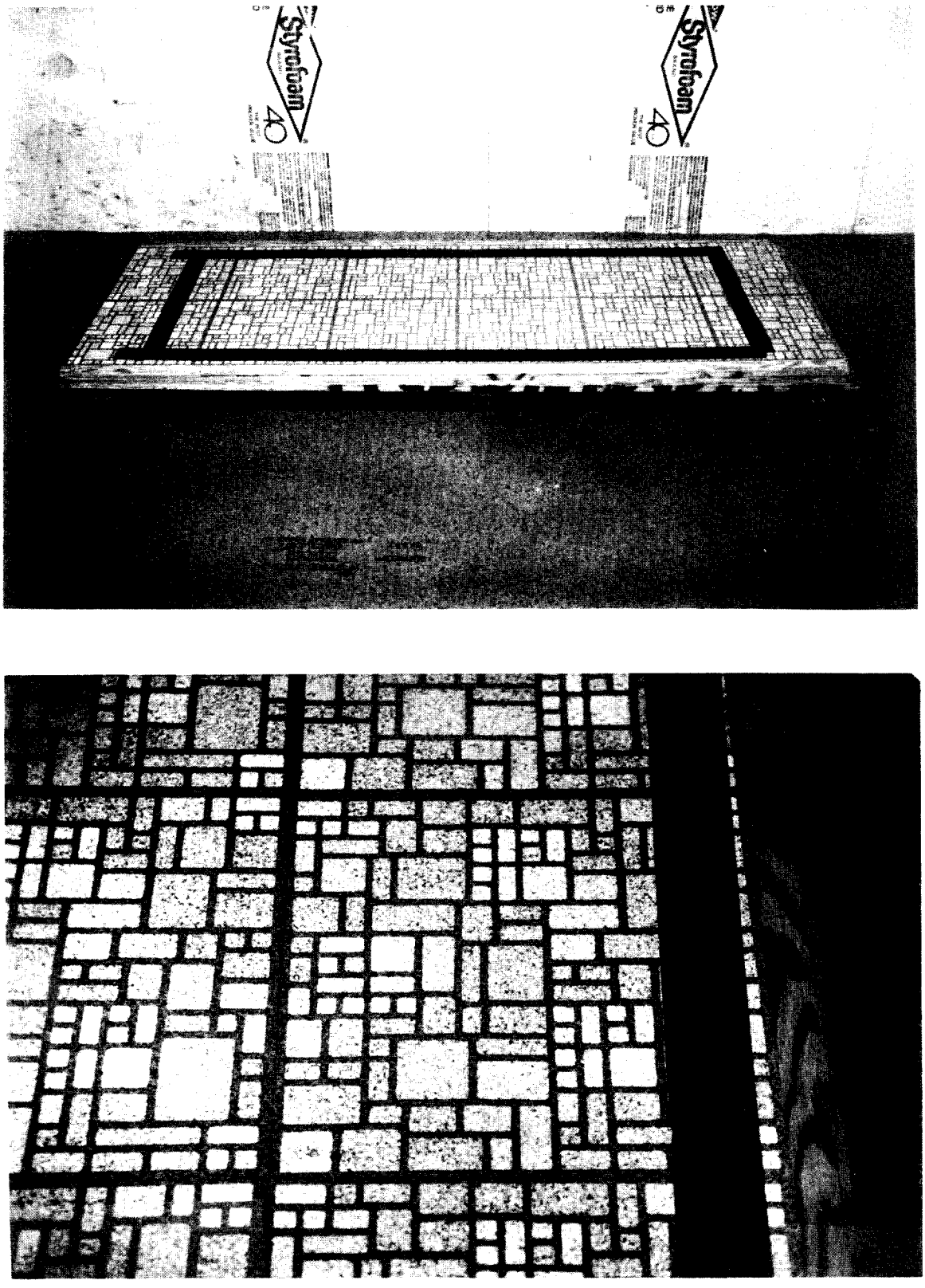


Figure 4-9 Tile substrate

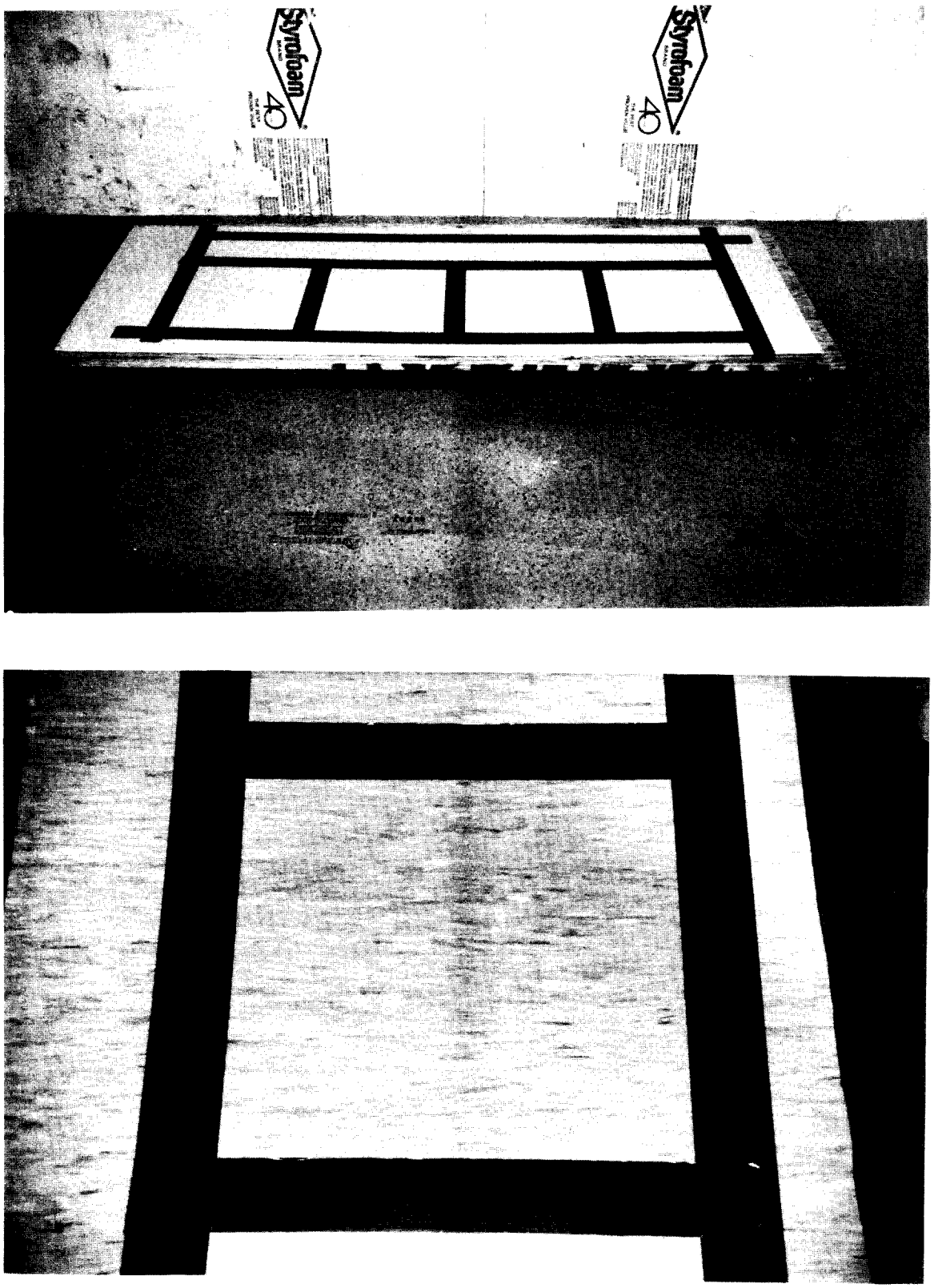


Figure 4-10 Linoleum (sheet vinyl) substrate

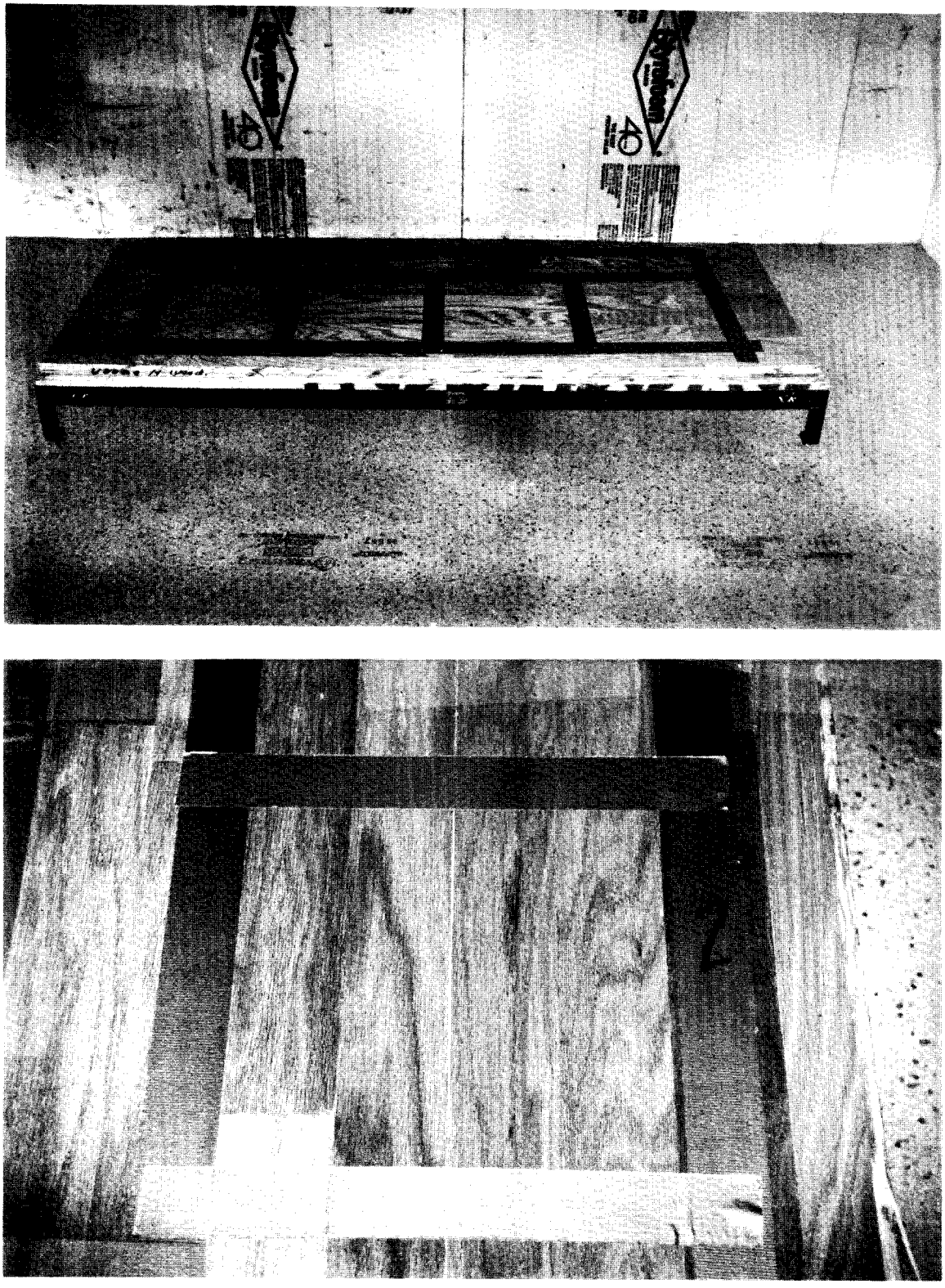


Figure 4-11 Wood flooring substrate

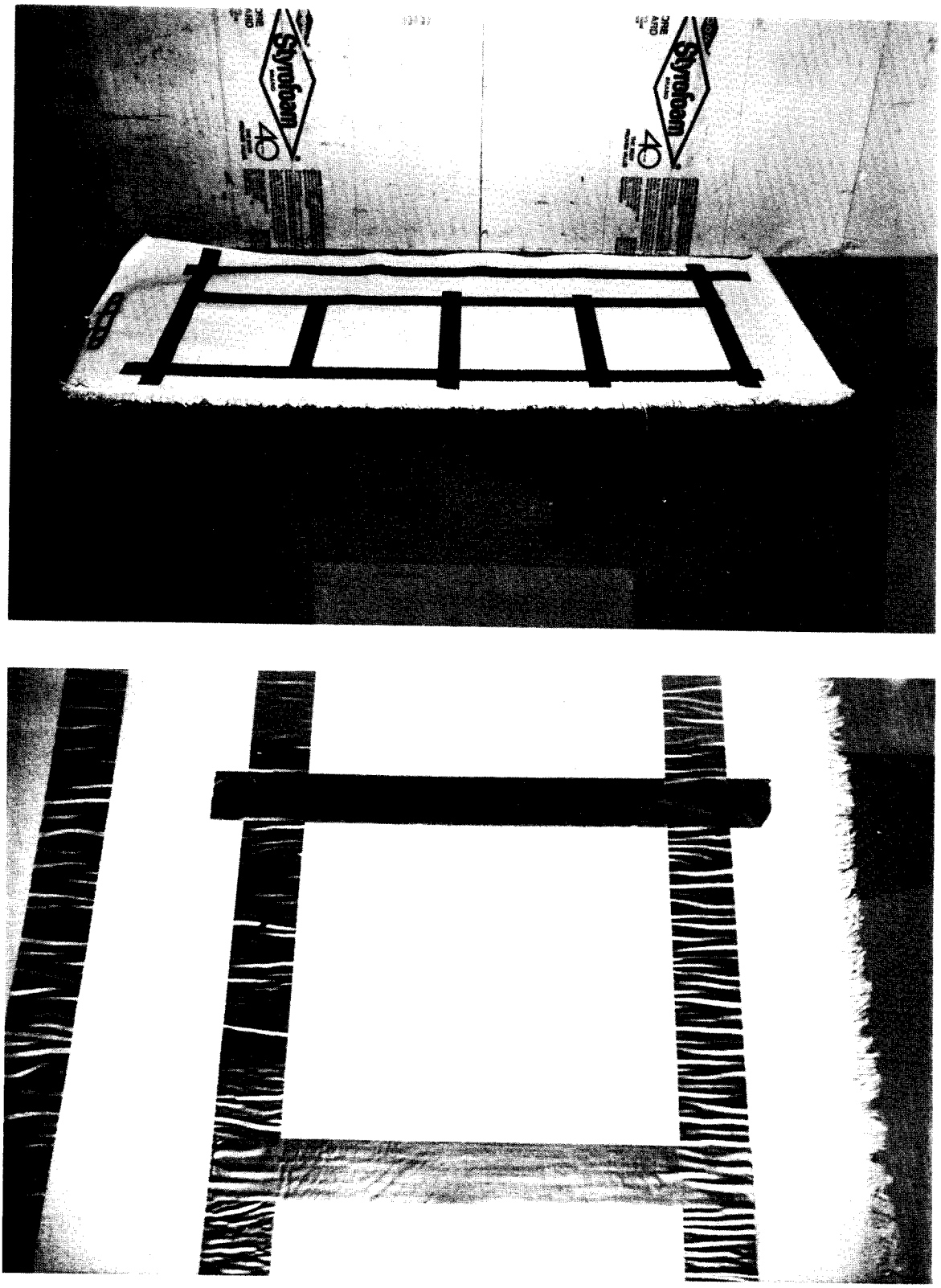


Figure 4-12 Upholstery substrate

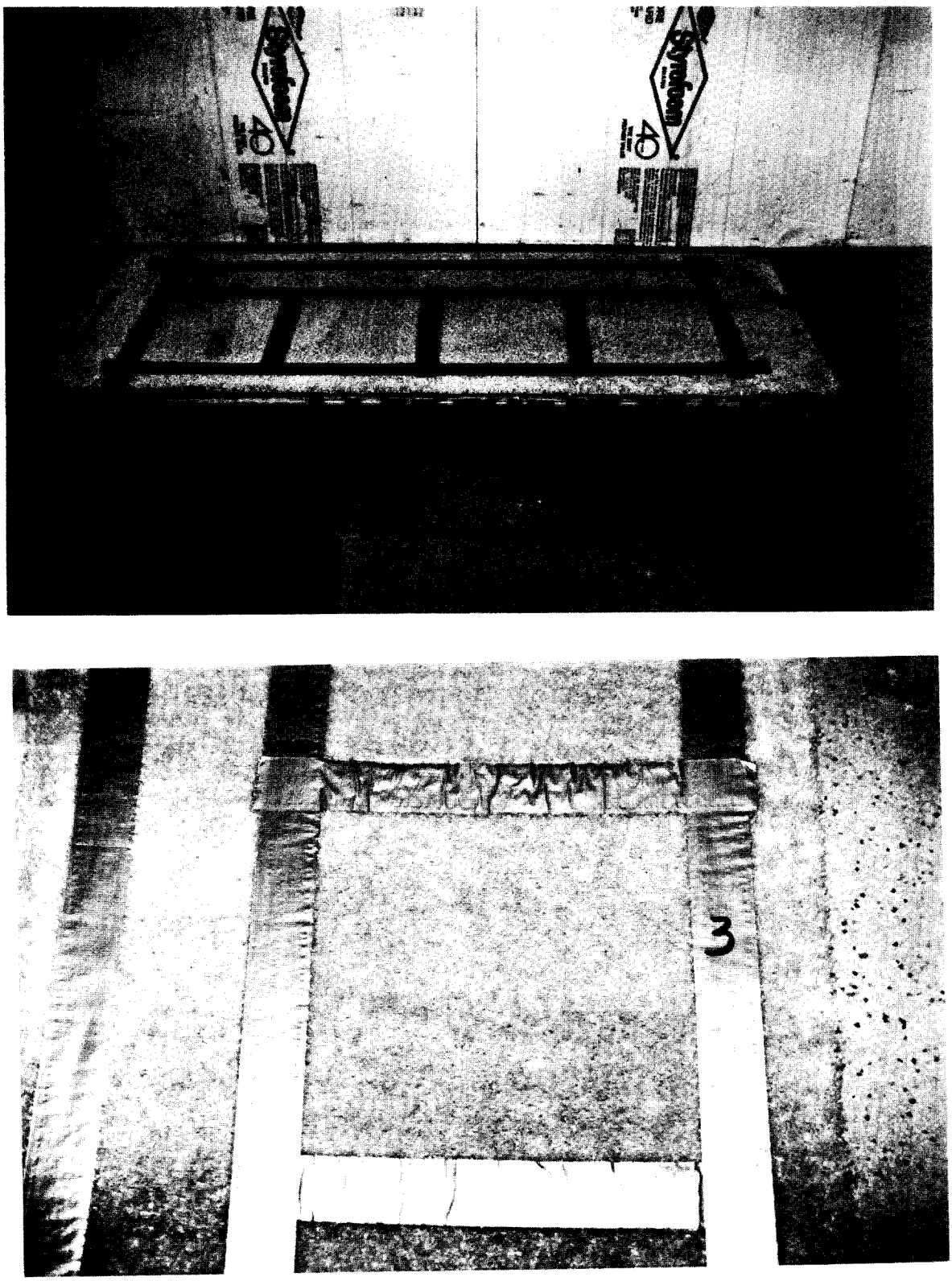


Figure 4-13 Carpet substrate

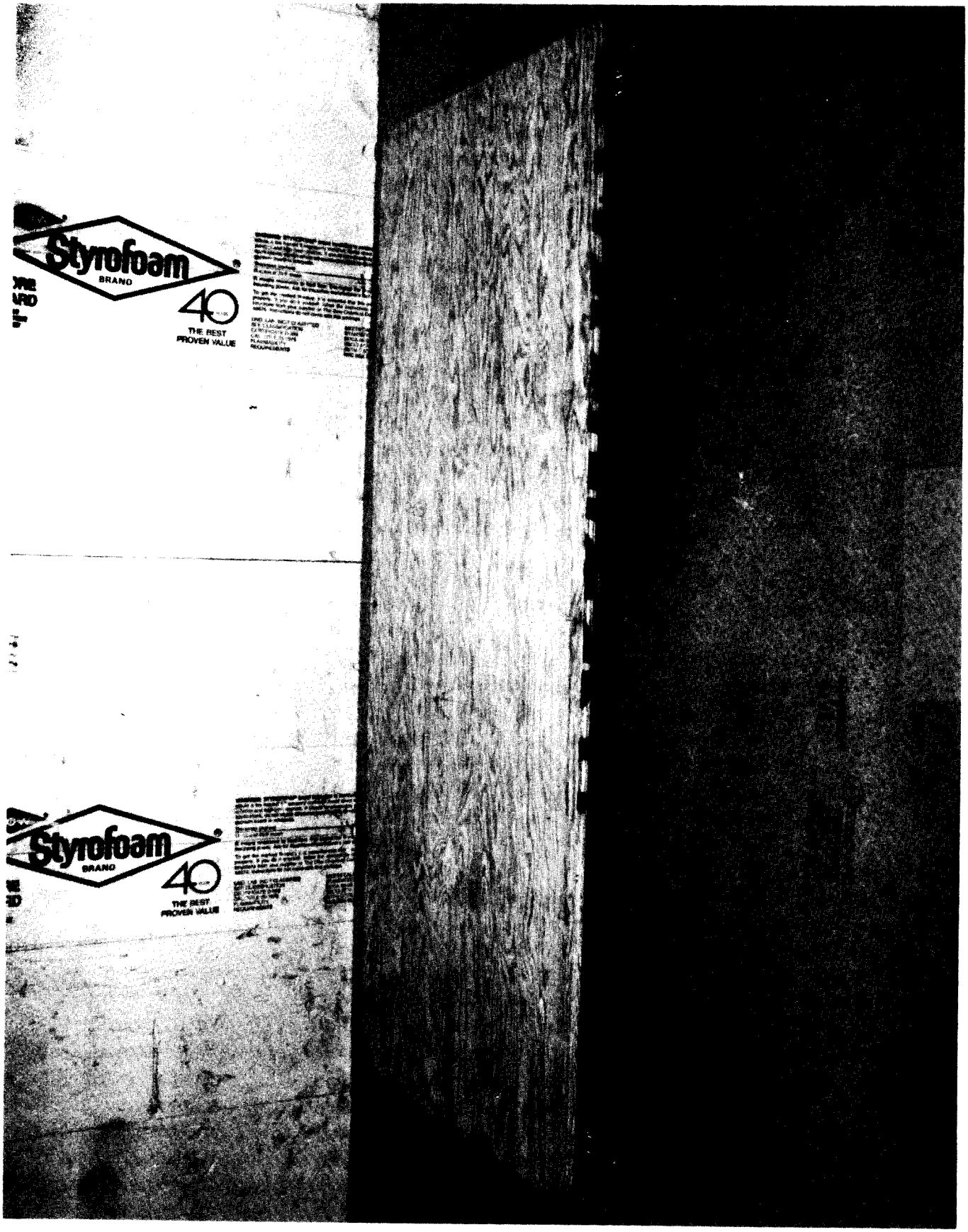


Figure 4-14 Platform for substrates

Carpet used for the tests, including carpet with ground-in dust, was a commonly used tufted cut pile type made of 100% staple nylon. A 3/8 inch thick foam pad was used underneath each carpet section. For the tests, the carpet was clamped to the platform at each of the four corners. The upholstery was 100% cotton, with a weight of 2.19 lbs. per linear yard 54 inches wide. The weave was "textures," a box weave with warp and filler yarns. A layer of 1/2 inch thick foam padding was used underneath each upholstery section. Upholstery substrates were stretched and clamped to the platform along both ends to prevent "rippling" of the surface when vacuumed.

New wood flooring purchased for this study consisted of 3-inch wide x 3/8-inch thick tongue and groove flooring available prestained and prewaxed. The flooring was glued onto a piece of 3/4 inch-thick plywood.

Tile substrates consisted of 12 x 12-in. squares of self-adhering vinyl tiles applied to a piece of 3/4 inch-thick plywood. The tile had a slight surface texture. The linoleum (i.e., sheet vinyl) substrate was glued onto a piece of 3/4 inch-thick plywood. This linoleum had a smooth surface.

The following list shows the sections which describe the sample collection procedures, including the preparatory steps, along with the dates when the work was carried out.

4.2 Description of House Dust Used in Study (7/27/93 to 8/19/93)
4.3 Fiber Preconditioning of Carpet and Upholstery (7/30/93 to 8/18/93)
4.4 Dust Preconditioning of All Substrates (8/23/93 to 8/25/93)
4.6 Vacuum Cleaner Tests (8/26/93 to 9/9/93)
4.7 Sampler Tests (9/10/93 to 9/15/93)
4.8 Vacuum Cleaner Exhaust Emission Testing (7/27/93 to 7/29/93)

NOTE: The pilot study, which included the vacuum cleaner exhaust emission testing, was carried out from 6/22/93 to 7/29/93. The pilot study report can be found in Appendix A.

4.2 Description of House Dust Used in Study

Vacuum cleaner dust bags from household vacuum cleaners were collected from homes within one of two age groups: built before 1963 (older homes) or built after 1982 (newer homes). Seventeen bags were collected from older homes and 20 from newer homes. The bags were donated by employees of EPA, Westat, and MRI. Other than stratifying homes by age, there was no control over the selection of homes or the collection of dust within the homes. The bags were then sent to Neutron Products in Maryland for sterilization.

Following sterilization, the dust bags from both older homes and newer homes were separately sieved into six particle size classes:

< 53 µm
53-106 µm
106-150 µm
150-212 µm
212-250 µm
250-2,000 µm

All material above 2,000 microns was weighed and then discarded. The dust size classes were selected to be similar to the size classes used in other studies and to minimize the quantity of dust required for the study by using all of the dust under 2,000 microns. All sieving was performed according to Appendix B in Volume II, "Protocol for Sieving Household Dust."

The size distribution across the six dust particle size classes for the dust from older homes and newer homes is summarized in Section 6.2.1 of this report. Samples of dust in each particle size class were analyzed for lead, and those results are summarized in Section 6.2.2.

In addition to taking samples of the sieved dust for the initial lead analysis, samples of each dust size were taken for lead analysis weekly during the vacuum cleaner and sampler tests. These dust samples were obtained by the same procedure used for distributing dust onto a substrate, except that the dust was distributed onto a sheet of plastic instead of a substrate. Dust deposited on the plastic was transferred into the sample bottle for analysis. Lead results for the initial analysis of sieved dust and the weekly samples are included in Appendix C.

4.3 Fiber Preconditioning of Carpet and Upholstery

Prior to any vacuum cleaner or sampler tests, the carpet and upholstery substrate sections were preconditioned, first by vacuuming the carpet and upholstery sections to remove fibers, and second by applying and vacuuming dust several times. The fiber preconditioning is described in this section. The dust preconditioning is described in Section 4.4.

The new carpet and upholstery substrate sections were preconditioned by several vacuumings (without applying dust) using all four vacuum cleaners. This was done to minimize the weight of fibers picked up during subsequent vacuum cleaner and sampler tests because the fibers could affect the measurement of dust recovery data as well as the lead concentration.

Fiber preconditioning of carpet and upholstery substrates was carried out in accordance with the test sequence attached to the "Protocol for Conditioning Carpet and Other Substrates" in Appendix D of Volume II. The preconditioning protocol specified repeated 5-minute vacuumings for a total of 20 vacuumings, or until the weight gain was 20 mg or less for four consecutive vacuumings. The preconditioning of carpet

involved many more vacuumings than originally anticipated because, in many cases, the weight gain after 20 vacuumings exceeded the 20-mg limit. There was also a problem with the vacuum cleaner bag changing weight with time, even without vacuuming, possibly due to changes in temperature and humidity. Thus, it was not clear how much of the weight gain problem when vacuuming carpet was due either to characteristics of the vacuum bags, or to pickup of material from the substrates, or both.

Because the weight problem was evident in the first two preconditioning tests (Tests 1 and 2), several procedural changes were made in an effort to correct the problem. The main procedural changes that were subsequently used in the preconditioning tests were:

- The bag was cooled for 2 minutes in the room's vent duct after use.

- The bag was brushed with an anti-static brush, placed in a plastic bag, and put on the balance. The weight reading was taken 1 minute after the bag was removed from cooling (total of 3 minutes after removal from vacuum cleaner). The bag remained in the plastic bag until needed again.

Fiber preconditioning of the four sections of upholstery (Tests 9 to 12) gave similar (and unexpected) results in that the incremental weight gain exceeded 20 mg after many vacuumings. For this cotton upholstery material, it was clear that the weight gain was primarily due to the material. Cotton fibers could easily be seen inside the vacuum cleaner bags. Copies of the data from these preconditioning tests are given in Appendix B of this report.

The limit of 20 mg of fiber per 5 minutes of vacuuming was set, based on the pilot study results, as a level which could be achieved and which would have a negligible effect on the recovery measurements. This target level was not achieved for all of the carpet and upholstery samples used in the full study. Nevertheless, the effect of fiber release on the weight of dust recovered from the substrates was small. In addition, the analysis included a correction for fiber release and dust carryover.

4.4 Dust Preconditioning of all Substrates

Dust preconditioning of all six substrate materials was carried out according to the test sequence attached to the "Protocol for Conditioning Carpet and Other Substrates" in Appendix D of Volume II. For each section of substrate, this procedure involved several applications of dust of different particle sizes, two different teams, and vacuuming for 40 seconds using a different vacuum cleaner each time.

For each of the six types of substrates, four sections of each type were necessary, because the tests included two different dust loadings (100 and 400 mg/ ft^2) and two different types of dust (i.e., dust from older homes-high lead, and dust from newer

homes-low lead). Therefore, the four sections of each substrate were identified for specific dust loadings and lead concentrations as:

- Low lead, low loading
- Low lead, high loading
- High lead, low loading
- High lead, high loading

Each substrate section was used for the appropriate dust preconditioning tests in accordance with the design sequence. The final design sequence for the dust preconditioning and data from these tests are given in Appendix B of this report.

4.5 Statistical Design

The study was designed to estimate main effects for operator, dust loading, nominal dust concentration, dust particle size, substrate, sampler or vacuum cleaner, and interactions between sampler and both substrate and dust particle size. In the original design, each combination of dust particle size and substrate shown in Table 4-2 was to be tested using each sampler.

The original experimental design was modified as a result of the pilot tests and, after beginning the full study, in response to budget pressures. After the tests for the full study began, it was necessary to cut back on the number of tests to stay within the budget for the project. The redesign of the study was performed quickly and consisted of specifying a fraction of the tests from the original design. In the redesign, the tile substrate was eliminated from further testing, and not all samplers were tested on each combination of substrate and dust particle size shown in Table 4-2.

The order of the tests was randomized in such a way that both operators could perform tests at the same time and the chances of both operator needing either the same substrate sample or the same sampler (or vacuum cleaner) at the same time were minimized.

Table 4-2 Combinations of substrate and dust particle class tested in the study

	Dust Particle Size Class					
Substrate	<53 μm	53-106 μm	106-150 μm	150-212 μm	212-250 μm	250-2,000 μm
Vinyl Tile (textured) (Tile was used only in the original design)	Tested	Tested	Not tested	Tested	Tested	Not tested
Sheet Vinyl/Linoleum (Smooth)	Tested	Tested	Tested	Tested	Tested	Tested
Wood	Tested	Tested	Tested	Tested	Tested	Tested
Upholstery	Tested, not using wipes	Tested, not using wipes	Not tested	Tested, not using wipes	Tested, not using wipes	Not tested
Carpet	Tested, not using wipes	Tested, not using wipes	Tested, not using wipes	Tested, not using wipes	Tested, not using wipes	Tested, not using wipes
Carpet with ground-in dust	Tested, not using wipes	Tested, not using wipes	Not tested	Tested, not using wipes	Tested, not using wipes	Not tested

4.6 Vacuum Cleaner Tests

Vacuum cleaner testing was carried out according to a specific test sequence. Four vacuum cleaners were tested for dust recovery and lead recovery.

Vacuum cleaners

Model A - Canister model with beater bar and without HEPA filter
Model B - Canister model with beater bar and without HEPA filter
Model C - Canister model with beater bar and with HEPA filter
Model D - Upright with beater bar and without HEPA filter

An original test sequence consisted of tests on 240 combinations of substrate, dust particle size class, dust loading, lead concentration, team, and vacuum cleaner. The original test sequence was revised during the course of the work as a result of budgetary limitations. The revised test sequences (85 vacuum cleaner tests) are shown in Tables 4-3 and 4-4. The revision of the original test pattern was guided by the preliminary results from the pilot tests and the dust preconditioning tests. In the revised test pattern, no tests with tile substrate, other than the initial tests, were to be performed. Also, fewer dust particle sizes were to be tested for each combination of substrate and vacuum cleaner. The revised test design designated the sequence for carrying out the tests and stipulated the parameters for each test, such as:

- Test Number
- Substrate
- Particle Size Class of Dust
- Dust Loading (100 or 400 mg/ft^2)
- Lead Concentration of Dust (High or Low)
- Team (Team 1 or Team 2)
- Vacuum Cleaner (A, B, C, or D)

Table 4-3 Test sequence for vacuum cleaner tests by team 1

Substrate	Particle Size Class	Dust Loading	Nominal Lead Conc	Vacuum	Original Number	Revised Number
Linoleum	53-106	400 mg/sq ft	High	A	1001	
Linoleum	<53	100 mg/sq ft	High	D	1002	
Linoleum	212-250	100 mg/sq ft	High	C	1003	
Linoleum	106-150	100 mg/sq ft	Low	B	1004	
Wood	150-212	400 mg/sq ft	High	A	1005	
Wood	106-150	400 mg/sq ft	Low	B	1006	
Wood	150-212	400 mg/sq ft	High	C	1007	1-28
Wood	<53	100 mg/sq ft	Low	D	1008	
Carpet	53-106	400 mg/sq ft	Low	D	1009	1-10
Carpet	53-106	400 mg/sq ft	Low	A	1010	
Carpet	53-106	400 mg/sq ft	Low	C	1011	
Carpet	53-106	400 mg/sq ft	Low	B	1012	
Carpet	<53	100 mg/sq ft	Low	C	1013	
Carpet	212-250	100 mg/sq ft	Low	D	1014	
Upholstery	<53	100 mg/sq ft	High	B	1020	1-1
Upholstery	<53	100 mg/sq ft	High	C	1085	1-2
Upholstery	212-250	100 mg/sq ft	High	B	1088	1-3
Carpet w Grind-in	212-250	100 mg/sq ft	High	A	1052	1-4
Carpet w Grind-in	212-250	100 mg/sq ft	High	B	1101	1-5
Carpet w Grind-in	<53	100 mg/sq ft	High	D	1104	1-6
Upholstery	53-106	400 mg/sq ft	High	D	1030	1-7
Upholstery	53-106	400 mg/sq ft	High	A	1032	1-8
Carpet	106-150	100 mg/sq ft	High	A	1046	1-9
Linoleum	212-250	100 mg/sq ft	High	D	1026	1-11
Linoleum	106-150	100 mg/sq ft	Low	C	1027	1-12
Linoleum	150-212	400 mg/sq ft	Low	B	1056	1-13
Carpet	<53	100 mg/sq ft	Low	A	1015	1-14
Carpet	212-250	100 mg/sq ft	Low	A	1083	1-15
Carpet w Grind-in	53-106	400 mg/sq ft	High	C	1069	1-16
Linoleum	<53	100 mg/sq ft	High	B	1075	1-17
Linoleum	53-106	400 mg/sq ft	High	C	1076	1-18
Linoleum	250-2000	400 mg/sq ft	High	B	1095	1-19
Upholstery	150-212	400 mg/sq ft	Low	B	1042	1-20
Upholstery	150-212	400 mg/sq ft	Low	A	1044	1-21
Carpet	250-2000	400 mg/sq ft	High	B	1065	1-22
Carpet	150-212	400 mg/sq ft	High	D	1119	1-23
Carpet w Grind-in	150-212	400 mg/sq ft	Low	B	1038	1-24
Wood	212-250	100 mg/sq ft	Low	B	1079	1-25
Wood	106-150	400 mg/sq ft	Low	D	1080	1-26

Wood	250-2000	100 mg/sq ft	High	A	1111	1-27
Wood	53-106	400 mg/sq ft	Low	B	1058	1-29
Wood	<53	100 mg/sq ft	Low	C	1077	1-30

Table 4-4 Test sequence for vacuum cleaner tests by team 2

Substrate	Particle Size Class	Dust Loading	Nominal Lead Conc	Vacuum	Original Number	Revised Number
Tile	150-212	100 mg/sq ft	Low	C	2001	
Tile	212-250	400 mg/sq ft	High	B	2002	
Tile	150-212	100 mg/sq ft	Low	A	2003	
Tile	<53	400 mg/sq ft	High	D	2004	
Carpet	212-250	400 mg/sq ft	High	C	2005	
Carpet	<53	400 mg/sq ft	High	D	2006	
Carpet	<53	400 mg/sq ft	High	A	2007	
Carpet	212-250	400 mg/sq ft	High	B	2008	
Carpet w Grind-in	212-250	400 mg/sq ft	Low	C	2009	
Carpet w Grind-in	212-250	400 mg/sq ft	Low	B	2010	
Carpet w Grind-in	<53	400 mg/sq ft	Low	D	2011	
Carpet w Grind-in	<53	400 mg/sq ft	Low	A	2012	2-1
Linoleum	53-106	100 mg/sq ft	Low	A	2013	
Linoleum	150-212	100 mg/sq ft	High	B	2014	
Carpet w Grind-in	212-250	400 mg/sq ft	Low	D	2098	2-2
Carpet w Grind-in	<53	400 mg/sq ft	Low	C	2099	2-3
Linoleum	250-2000	100 mg/sq ft	Low	C	2033	2-4
Linoleum	<53	400 mg/sq ft	Low	A	2048	2-5
Linoleum	53-106	100 mg/sq ft	Low	D	2061	2-6
Carpet	53-106	100 mg/sq ft	High	C	2106	2-7
Upholstery	53-106	100 mg/sq ft	Low	C	2025	2-8
Wood	212-250	400 mg/sq ft	High	C	2065	2-9
Wood	53-106	100 mg/sq ft	High	A	2068	2-10
Wood	<53	400 mg/sq ft	High	D	2095	2-11
Carpet w Grind-in	150-212	100 mg/sq ft	High	A	2109	2-12
Carpet w Grind-in	150-212	100 mg/sq ft	High	C	2112	2-13
Wood	106-150	100 mg/sq ft	High	B	2018	2-14
Wood	150-212	100 mg/sq ft	Low	A	2020	2-15
Wood	250-2000	400 mg/sq ft	Low	D	2052	2-16
Linoleum	212-250	400 mg/sq ft	Low	A	2064	2-17
Linoleum	150-212	100 mg/sq ft	High	D	2085	2-18
Linoleum	106-150	400 mg/sq ft	High	A	2088	2-19
Carpet w Grind-in	53-106	100 mg/sq ft	Low	D	2043	2-20
Carpet w Grind-in	53-106	100 mg/sq ft	Low	B	2044	2-21
Carpet	212-250	400 mg/sq ft	High	D	2058	2-22
Carpet	<53	400 mg/sq ft	High	B	2060	2-23
Upholstery	<53	400 mg/sq ft	Low	D	2089	2-24
Upholstery	212-250	400 mg/sq ft	Low	C	2091	2-25
Upholstery	212-250	400 mg/sq ft	Low	A	2101	2-26

Upholstery	150-212	100 mg/sq ft	High	D	2078	2-27
Carpet	106-150	400 mg/sq ft	Low	C	2071	2-28
Carpet	150-212	100 mg/sq ft	Low	B	2022	2-29
Carpet	250-2000	100 mg/sq ft	Low	C	2074	2-30

Each test involved the following procedure:

- Tare weigh vacuum cleaner bag (after run free for 40 sec)
- Vacuum substrate for 40 sec and weigh bag
- Apply dust, vacuum 40 sec, weigh bag
- Apply dust, vacuum 40 sec, weigh bag
- Apply dust, vacuum 40 sec, weigh bag
- Vacuum substrate and weigh bag
- Vacuum substrate and weigh bag
- Vacuum substrate and weigh bag
- Recover dust from bag, weigh and submit for lead analysis

As shown above, each test involved three applications of dust, followed by vacuuming and weighing, and then three additional vacuumings and weighings. The dust from the bags was recovered after the last vacuuming by holding the bag upside down with the dust inlet opening positioned over a wide-mouth sample bottle. When the bag was tapped, part of the dust in the bag fell into the sample bottle; thus only part of the dust in the bag was recovered for lead analysis.

Application of dust onto the substrates was begun by weighing the required amount of dust into a small beaker. The application technique involved pouring the dust from the beaker onto the appropriate size sieve screen while tapping the sieve as it was moved around above the substrate. This technique provided the most even distribution of dust onto the substrate, but some small amount of dust always remained on the sieve. The weight of the dust applied, therefore, was determined by weighing the sieve and beaker together, before and after application.

For carpet with grind-in, the dust was applied and then ground in using the ASTM method described in Appendix C of Volume II. An example of the data for one vacuum cleaner test is provided in Appendix E in this volume, along with a printout of the database for all the vacuum cleaner sampling tests.

4.7 Sampler Tests

Sampler tests were similar to the vacuum cleaner tests except that the test area was only one square foot. Therefore, the weight of dust applied was less than that applied in vacuum cleaner tests since the dust loading used was the same for vacuum cleaner and

sampler tests (100 and 400 mg/ ft^2). Only one application of dust, rather than three, was used in sampler tests. As with the vacuum cleaner tests, the original number of sampler tests was reduced from 161 to 52 due to budgetary constraints.

The three vacuum samplers were tested for dust recovery and all four were tested for lead recovery. As mentioned previously, the four samplers were:

- Wipes
- BRM sampler (BRM)
- CAPS sampler (CAPS)
- Blue Nozzle sampler

As for the vacuum cleaner tests, the test design designated the sequence for carrying out the tests and stipulated the parameters for each test, such as :

- Test Number
- Substrate
- Dust Particle Size Class
- Dust Loading (100 or 400 mg/ft^2)
- Lead Concentration of Dusts (High or Low)
- Team (Team 1 or Team 2)
- Sampler (wipe, BRM, CAPS, or Blue Nozzle)
- Square Number to Be Used (1, 2, 3, or 4). The "square number" to be used in each test referred to four one square foot squares marked on each section of substrate.

Prior to the first sampler test on any substrate section, the entire test area (54 x 18 in) was vacuumed for 40 seconds with vacuum cleaner A. This procedure helped to minimize the effect of any dust that might remain from the previous vacuum cleaner tests. The same substrates were used for both the vacuum cleaner and sampler tests, with all the vacuum cleaner tests being done first.

Following the last sampler test on any substrate section, the entire test area was vacuumed for 120 seconds with vacuum cleaner A. This was done to determine the weight of material picked up by the vacuum cleaner after the sampler tests. That is,

vacuuming was done for 120 seconds to simulate the three final 40-second vacuumings done in each vacuum cleaner test.

Considering the above, each sampler test involved the following procedure:

- Only if first square is to be used (i.e., square 1):
    - Reweigh bag (vacuum cleaner A)
    - Vacuum entire substrate for 40 seconds with vacuum cleaner A
    - Reweigh bag
- Deposit dust in specified square (i.e., square 1, 2, 3, or 4)
- Use specified sampler to sample dust
- Weigh the dust collected by the sampler (except wipes)
- Prepare the dust sample for analysis
- If last square is to be used (i.e., square 4 for all substrates except carpet; last square for carpet is square 3 since wipes are not done on carpet):
    - Tare weigh bag (vacuum cleaner A)
    - Vacuum entire substrate for 120 seconds with vacuum cleaner A
    - Reweigh bag
    - Vacuum dust from wand and brush of vacuum cleaner A (no weighing)

Application of dust onto the 1-ft^2 test area was done using the same procedure described for vacuum cleaner tests. Grind-in, when specified, was done as per Appendix C of Volume II, but only over the one foot square test area.

Dust samples from the samplers were recovered for lead analysis. For wipes, the entire wipe was submitted to the lab. Dust was recovered from the BRM and CAPS sampler using the procedures described in the appendices in Volume II. For the Blue Nozzle sampler, the entire filter cartridge was transferred so that analysts could remove the filter for digestion and analysis.

The sampler tests were carried out in accordance with the test sequence shown in Tables 4-5 and 4-6. Tests with individual samplers were done using the procedures in Volume II.

Table 4-5 Test sequence for sampler tests by team 1

Substrate	Particle Size Class	Dust Loading	Nominal Lead Conc	Vacuum	Square	Revised Number
Carpet	53-106	400 mg/sq ft	Low	BRM	4	3-1
Upholstery	<53	100 mg/sq ft	High	CAPS cyclone	2	3-2
Upholstery	<53	100 mg/sq ft	High	Blue Nozzle	3	3-3
Upholstery	212-250	100 mg/sq ft	High	Blue Nozzle	4	3-4
Upholstery	150-212	400 mg/sq ft	Low	Blue Nozzle	3	3-5
Wood	106-150	400 mg/sq ft	Low	BRM	2	3-6
Wood	53-106	400 mg/sq ft	Low	Blue Nozzle	3	3-7
Carpet	150-212	400 mg/sq ft	High	BRM	1	3-8
Carpet	250-2000	400 mg/sq ft	High	Blue Nozzle	2	3-9
Carpet w Grind-in	53-106	400 mg/sq ft	High	CAPS cyclone	3	3-10
Carpet w Grind-in	150-212	400 mg/sq ft	Low	Blue Nozzle	1	3-11
Wood	150-212	400 mg/sq ft	High	CAPS cyclone	4	3-12
Linoleum	106-150	100 mg/sq ft	Low	CAPS cyclone	2	3-13
Wood	212-250	100 mg/sq ft	Low	Blue Nozzle	1	3-14
Wood	<53	100 mg/sq ft	Low	CAPS cyclone	2	3-15
Upholstery	53-106	400 mg/sq ft	High	BRM	3	3-16
Linoleum	250-2000	400 mg/sq ft	High	Blue Nozzle	1	3-17
Linoleum	53-106	400 mg/sq ft	High	CAPS cyclone	2	3-18
Carpet w Grind-in	212-250	100 mg/sq ft	High	Blue Nozzle	2	3-19
Carpet w Grind-in	<53	100 mg/sq ft	High	BRM	3	3-20
Linoleum	<53	100 mg/sq ft	High	Blue Nozzle	3	3-21
Linoleum	212-250	100 mg/sq ft	High	BRM	4	3-22
Linoleum	150-212	400 mg/sq ft	Low	Blue Nozzle	4	3-23
Wood	250-2000	100 mg/sq ft	High	Baby Wipe	4	3-24

Table 4-6 Test sequence for sampler tests by team 2

Substrate	Particle Size Class	Dust Loading	Nominal Lead Conc	Vacuum	Square	Revised Number
Linoleum	212-250	400 mg/sq ft	Low	Baby Wipe	1	4-1
Linoleum	<53	400 mg/sq ft	Low	Baby Wipe	2	4-2
Carpet	53-106	100 mg/sq ft	High	CAPS cyclone	1	4-3
Carpet	<53	400 mg/sq ft	High	Blue Nozzle	3	4-4
Carpet	212-250	400 mg/sq ft	High	BRM	4	4-5
Carpet w Grind-in	<53	400 mg/sq ft	Low	CAPS cyclone	1	4-6
Carpet w Grind-in	212-250	400 mg/sq ft	Low	BRM	2	4-7
Linoleum	106-150	400 mg/sq ft	High	Baby Wipe	4	4-8
Upholstery	53-106	100 mg/sq ft	Low	CAPS cyclone	4	4-9
Upholstery	<53	400 mg/sq ft	Low	BRM	1	4-10
Upholstery	212-250	400 mg/sq ft	Low	CAPS cyclone	2	4-11
Carpet w Grind-in	53-106	100 mg/sq ft	Low	Blue Nozzle	1	4-12
Carpet w Grind-in	53-106	100 mg/sq ft	Low	BRM	2	4-13
Wood	150-212	100 mg/sq ft	Low	Baby Wipe	2	4-14
Linoleum	150-212	100 mg/sq ft	High	BRM	1	4-15
Carpet w Grind-in	150-212	100 mg/sq ft	High	CAPS cyclone	1	4-16
Linoleum	250-2000	100 mg/sq ft	Low	CAPS cyclone	2	4-17
Linoleum	53-106	100 mg/sq ft	Low	BRM	3	4-18
Carpet	250-2000	100 mg/sq ft	Low	CAPS cyclone	1	4-19
Carpet	150-212	100 mg/sq ft	Low	Blue Nozzle	2	4-20
Wood	<53	400 mg/sq ft	High	BRM	2	4-21
Wood	212-250	400 mg/sq ft	High	CAPS cyclone	3	4-22
Upholstery	150-212	100 mg/sq ft	High	BRM	3	4-23
Wood	53-106	100 mg/sq ft	High	Baby Wipe	2	4-24
Wood	106-150	100 mg/sq ft	High	Blue Nozzle	3	4-25
Wood	250-2000	400 mg/sq ft	Low	BRM	2	4-26
Carpet	106-150	400 mg/sq ft	Low	CAPS cyclone	3	4-27

An example of the sampling data for one test is provided in Appendix D of this volume, along with a printout of the sampling database for all the sampler tests.

4.8 Vacuum Cleaner Exhaust Emission Testing

A series of tests were performed with all four vacuum cleaners to measure exhaust dust concentrations. These tests, carried out during the pilot study, are documented in their entirety in the final report for the pilot study (see Appendix A) and results are summarized in Section 8 of this report. The procedures used in the tests are given in Volume II, Appendix O.

5 LABORATORY ANALYSIS PROCEDURES

Dust samples collected in this study were digested with nitric acid (HNO_3) and then analyzed for lead by Inductively Coupled Plasma (ICP) or Graphite Furnace Atomic Absorption (GFAA). The following samples were collected:

- Sieved dust samples
- Dust samples recovered from vacuum cleaner tests
- Dust samples recovered from sampler tests (including wipes and filter cassettes from Blue Nozzle sampler)

Wipe samples were digested using the procedure in Appendix J of Volume II. All other samples were digested using the procedure in Appendix K of Volume II. The digests were all analyzed by ICP per Appendix L of Volume II, except that the filters from the Blue Nozzle sampler were analyzed by GFAA. Also, two dust samples and one wipe sample were analyzed by GFAA because the ICP results were below 0.1 µg/mL.

5.1 Lead Analysis of Sieved Dust

At the onset of this study, the dust to be used during testing was sieved and composited into six particle size classes (see Section 4.2), separately for newer and older homes. Duplicate samples were taken from each the six size categories and were analyzed for lead content (i.e., initial analysis).

In addition to the initial analysis of the sieved dust samples, samples that simulated application of dust onto a substrate were taken each week for lead analysis.

The analytical results from all these sieved dust analyses are provided in Appendix C of this report.

5.2 Lead Analysis of Dust Samples from Vacuum Cleaner and Sampler Tests

All dust samples obtained from the sampler and vacuum cleaner tests were analyzed for lead per the digestion and analysis procedures noted above. The analytical results are summarized in Appendices D and E of this report.

6 RESULTS

6.1 Summary of Results from the Pilot and Preconditioning Data

6.1.1 Pilot Test Results

The pilot tests were conducted to answer questions which would help improve the study design. The tests provided data on fiber collection, dust recovery, and factors which affect the test procedures. Details of the pilot study are presented in Appendix A. The pilot tests consisted of five tasks. Results from Tasks 1 and 2 of the pilot study, those that affect only the test procedures for the full study, are discussed in the appendix. The results for the dust emission tests (Task 5) are summarized in Section 6.4.4. Other results from the pilot study which are relevant to the objectives of the full study are summarized here. Only vacuum cleaner A was used in the pilot tests.

In Tasks 3 and 4 of the pilot study, the estimated dust recovery for vacuum cleaner A was 84% (with 95% confidence interval from 80% to 87%) on carpets and 79% (with 95% confidence interval from 74% to 85%) on carpets with ground-in dust. Most of this dust is recovered in the first 40 seconds of vacuuming. For dust deposited on carpets, 80% is recovered in the first 30 seconds of vacuuming, 4% is recovered in successive vacuumings, and 16% is either caught in the carpet or lost. For dust deposited and ground into carpets, 68% is recovered in the first 30 seconds of vacuuming, 12% is recovered in successive vacuumings, and 20% is either caught in the carpet or lost. In the emission tests, 0.02% or less of the dust was found to pass through the vacuum cleaner bags.

From these figures it can be seen that roughly 16% to 20% of the dust deposited onto carpets is not accounted for. Common sense suggests that this dust might be (1) in the carpet and very difficult to remove with vacuuming, (2) below the carpet, having passed through the carpet, (3) in the air, (4) scattered around the testing room, perhaps onto parts of the carpet which were not in the vacuumed area, as a result of disturbance while depositing the dust, grinding the dust into the carpet, or vacuuming, or (5) caught in parts of the vacuum other than the bag. These preliminary results are consistent with the results from the full study.

The precision of the dust recovery measurements was better than anticipated during the preparation of the QAPjP. Therefore, the study as originally designed could have achieved the data quality objectives. Due to subsequent budget considerations, the number of tests planned for the full study was reduced. With this reduction it was anticipated that the original data quality objectives would still be achieved based on the precision attained in the pilot tests.

6.1.2 Preconditioning Results

The fiber and dust preconditioning steps prepared the substrate samples to be used in the sampler and vacuum cleaner tests. All four vacuum cleaners were used for preconditioning the substrates. Successive vacuumings were used to remove loose fibers from the carpet and upholstery substrates. The data suggest that the weight gain due to fibers can be substantially reduced with 30 minutes of vacuuming. However, the vacuum cleaners continue to pick up additional fibers after as much as four hours of vacuuming. Therefore, the analysis of the sampler and vacuum cleaner data included factors to account for fibers.

The average dust recovery achieved in the dust preconditioning ranged from 67% on carpet and upholstery, using vacuum cleaner C, to 98% on carpet and upholstery using vacuum cleaner A. Recovery on smooth substrates, wood, tile, and linoleum, was similar for all vacuum cleaners and averaged 94%. The precision of the dust recovery measurements depended on the substrate. Across all substrates, the pooled standard deviation is 17%. This is greater than the value of 10% that was assumed for the study redesign and suggested by the pilot study results.

6.2 Test Dust Characteristics

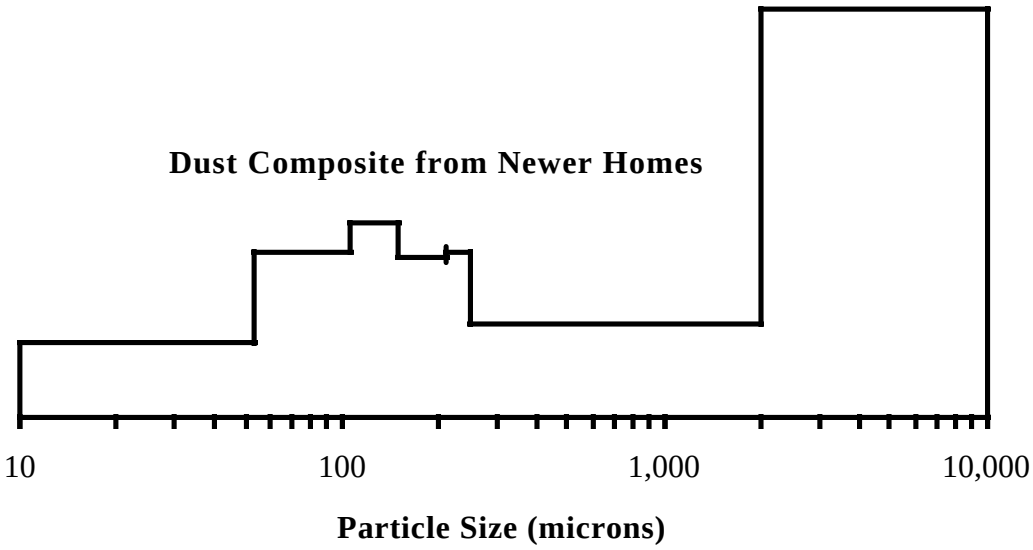
6.2.1 Dust Recovery by Particle Size Class for Older and Newer Homes

The dust in this study came from donated vacuum cleaner bags which were used in either older homes built before 1963, or newer homes built after 1982. The dust was removed from the vacuum cleaner bags and sieved into the seven dust particle size classes shown in Table 6-1. Dust from homes in the same age class and the same particle size class was physically mixed and placed in a plastic bag. For dust from both older and newer homes, Table 6-1 shows the weight of dust in each particle size class as a percentage of the weight of all dust removed from the bags.

The distribution of dust among the particle size classes is very similar for the samples collected from older homes and newer homes. Most of the dust was found in the smallest and largest size classes. The percent of dust in different size classes depends on the definition of the size class boundaries. The selection of the sieve sizes was based on what sieve sizes were available and size classes used in other studies. Figure 6-1 shows histograms of dust weight by size class using a continuous scale for the dust size. A log scale for the dust size was selected for the histograms because the distribution was more symmetric. Figure 6-1 shows the distribution of the dust weight by size in a manner which is relatively independent of the boundaries of the size classes. However, in order to plot the histogram, the lower end of the smallest size class (<53 μm) and the upper end of the largest size class (>2,000 μm) had to be specified. These limits were arbitrarily set at 10 μm and 10,000 μm respectively. Changing these limits does not greatly affect the shape of the distributions.

Table 6-1 Percent of dust in each particle size class, for older and newer homes

	Dust particle size (μm)	Dust weight (grams)	Percent of total
Dust from newer homes (built after 1982)	<53	1,052	10.1%
	53-106	967	9.3%
	106-150	566	5.4%
	150-212	470	4.5%
	212-250	231	2.2%
	250-2,000	1,645	15.8%
	>2,000	5,492	52.7%
	Total	10,424	100.0%
Dust from older homes (built before 1963)	<53	1,398	13.2%
	53-106	987	9.3%
	106-150	462	4.4%
	150-212	484	4.6%
	212-250	202	1.9%
	250-2,000	1,623	15.3%
	>2,000	5,438	51.3%
	Total	10,594	100.0%



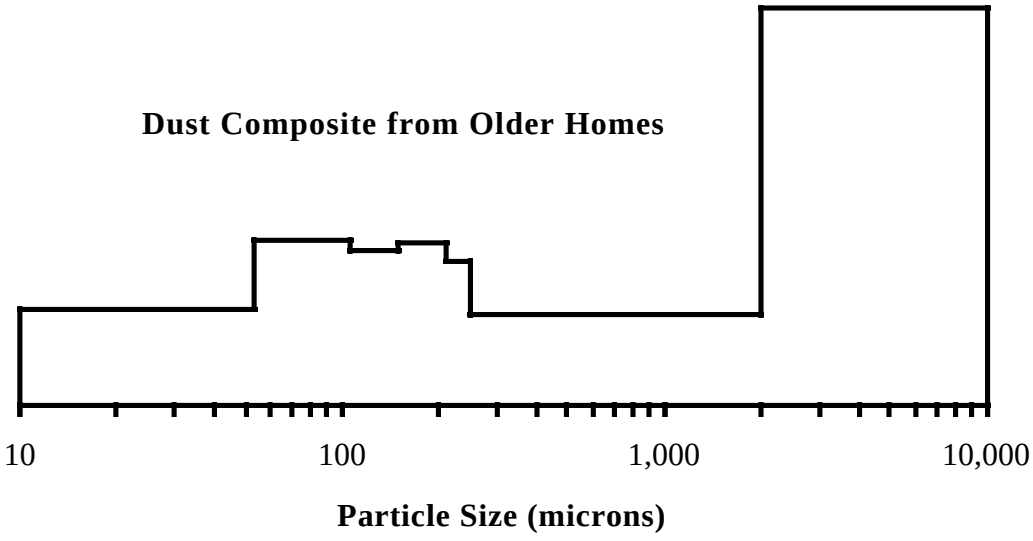


Figure 6-1 Histogram of relative dust weight by dust particle size for composite dust samples from newer and older homes

6.2.2 Lead Concentration by Particle Size Class for Older and Newer Homes

Samples of the dust from the six smallest particle size classes used in the study and from the two ages of homes were analyzed for lead concentration. Before the study began, duplicate grab samples of dust were taken from each bag after mixing the dust within the bag. These grab samples were then analyzed for their lead content. As the study progressed, samples of dust were collected periodically to measure the lead concentration in the dust actually deposited onto the substrates and to determine if the concentration changed over time due to settling or stratification in the bags of dust.

For the dust collected for this study (not involving a statistical sample of homes), the dust lead concentrations in dust from the older homes were significantly greater than those from newer homes. For dust from older homes, the lead concentration was similar for all size classes of dust except for the largest size which had the highest lead concentration. For dust from newer homes, lead concentrations were highest in the smallest dust particle classes. Figure 6-2 and Table 6-2 show the geometric mean lead concentrations and 95% confidence intervals for the twelve bags of dust used in the study. The spacing along the horizontal axis of Figure 6-2 is corresponds to using a log scale.

The dust lead concentration in the dust at the beginning of the study was combined with the measurements on the weight of dust to determine the amount of lead by dust particle size. Figure 6-3 shows the distribution of lead by particle size for dust from newer and older homes. The vertical scale is the same for both plots in Figure 6-3. For dust from newer homes, most of the lead is concentrated in particles with sizes below 250 μm. The lead in dust from older homes is distributed among all sizes of dust. For particle sizes less than 2,000 μm, the dust lead concentration in the dust from homes built after 1982 is 61 μg/g and, for homes built before 1963, is 474 μg/g.

6.3 Samplers

The sampler tests involved depositing a known amount of dust over a one-square foot area of the substrate, using the sampler to recover the dust following standard procedures for each sampler, and determining the weight of dust (gravimetric data) and amount of lead recovered. These measurements were used to calculate the dust recovery, lead recovery, and ratio of the lead concentration in the dust collected by the sampler and the lead concentration in the dust deposited on the substrate. The four samplers studied were the CAPS cyclone, BRM, Blue Nozzle, and baby wipes. The wipes were not tested on upholstery, carpet, or carpet with ground-in dust substrates. Also, only lead recovery could be determined for wipes.

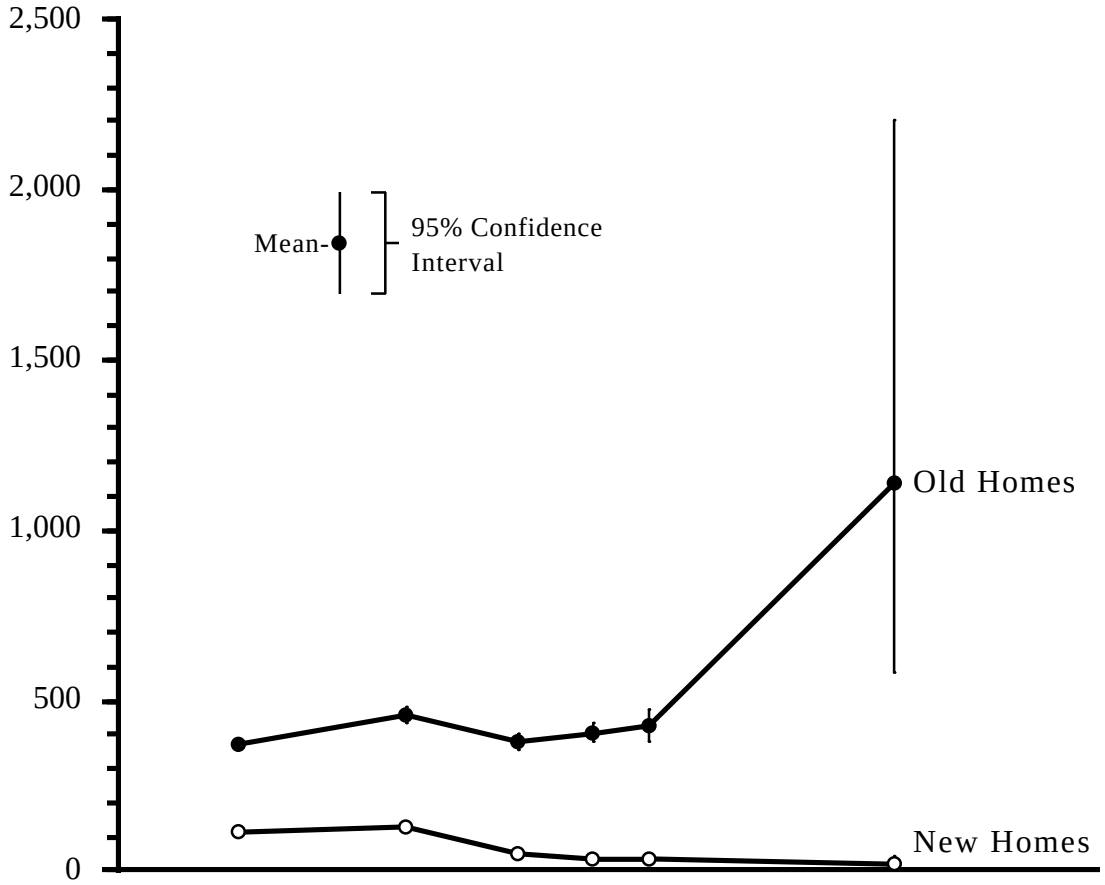


Figure 6-2 Geometric mean dust lead concentration by dust particle size, with approximate 95% confidence interval

Table 6-2 Geometric mean dust lead concentration (µg/g) by dust particle size, with approximate 95% confidence intervals

	Geometric mean dust lead concentration (µg/g)	
Dust Particle Size (µm)	Newer Homes	Older Homes
<53	110 (104 to 117)	374 (359 to 390)
53-106	131 (123 to 140)	457 (435 to 480)
106-150	48 (44 to 53)	383 (360 to 407)
150-212	34 (30 to 37)	405 (377 to 436)
212-250	32 (28 to 38)	424 (380 to 474)
250-2,000	21 (11 to 40)	1,136 (586 to 2,204)

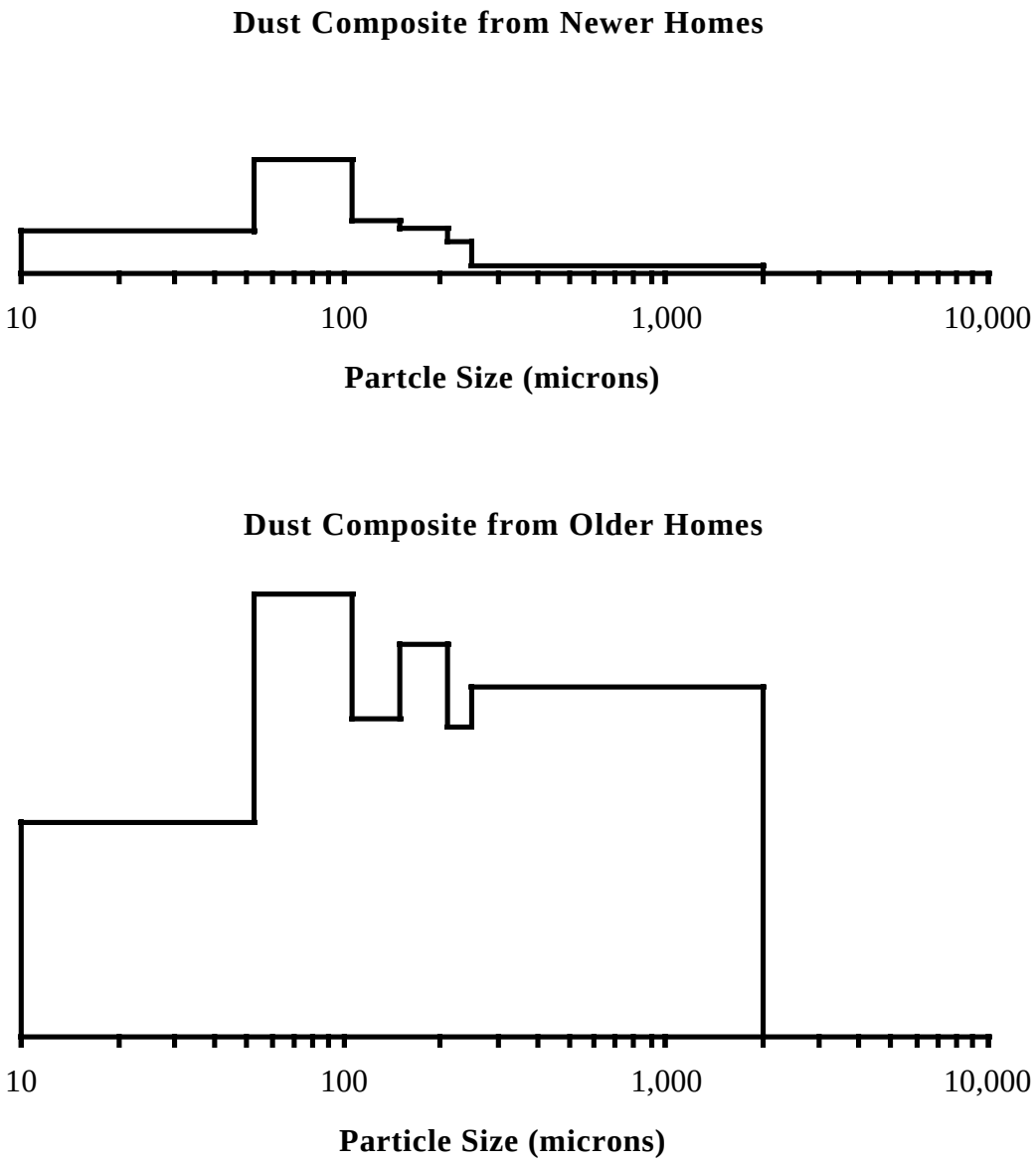


Figure 6-3 Histogram of relative lead weight by dust particle size for composite dust samples from newer and older homes

The study included sampler tests using each sampler, each substrate, and dust from each dust particle size class. However, not all combinations of these factors were tested. As a result, the statistical results are based on mathematical models. The estimates from the models (called least square means) are presented in this section. In the modeling, the effects of dust loading, nominal dust concentration (dust from newer or older homes), operator, substrate, sampler, and dust particle size class were tested along with tests of interactions, in particular, differences in sampler recovery with different dust particle sizes, and different substrates. In some cases regression weights were used to adjust for differences in measurement variance. This section discusses the estimates for only those factors which are statistically significant at the 5% level. A more complete discussion of the statistical models is presented in Section 8.

6.3.1 Sampler Dust Recovery

The sampler dust recovery is the weight of dust collected by the sampler as a percentage of the weight of dust deposited on the substrate. Based on a weighted analysis, the statistically significant predictors of dust recovery are the sampler type ($p < 0.0001$) and the combination of sampler and dust particle size ($p = 0.038$).

The average dust recovery for each sampler (with 95% confidence interval) is 30% (14% to 47%) for the Blue Nozzle sampler, 84% (79% to 89%) for the CAPS cyclone sampler, and 89% (82% to 96%) for the BRM sampler. These average sampler dust recoveries and the associated 95% confidence intervals are shown in Figure 6-4 and Table 6-3. The recovery estimate is shown as a dark circle in the figure. The vertical line through the circle shows the range of the 95% confidence interval on the estimated recovery. The standard deviations of the dust recovery measurements for the Blue Nozzle, CAPS cyclone, and BRM samplers are 29%, 12%, and 9%, respectively.

For each sampler, the dust recovery depends on the dust particle size, as shown in Figure 6-5 and Table 6-4. The plotting position for the dust particle size classes on the horizontal axis of Figure 6-5 is equivalent to using a log scale. The dust recovery for the Blue Nozzle sampler decreases as the particle size increases. The dust recovery for the CAPS cyclone and BRM sampler increases slightly or remains constant as the dust particle size increases. The estimated average dust recovery is the recovery for dust which has equal proportions of dust from each of the six dust particle size classes. In any situation, the dust recovery will vary, particularly for the Blue Nozzle sampler, depending on the relative proportion of dust in each dust particle size class.

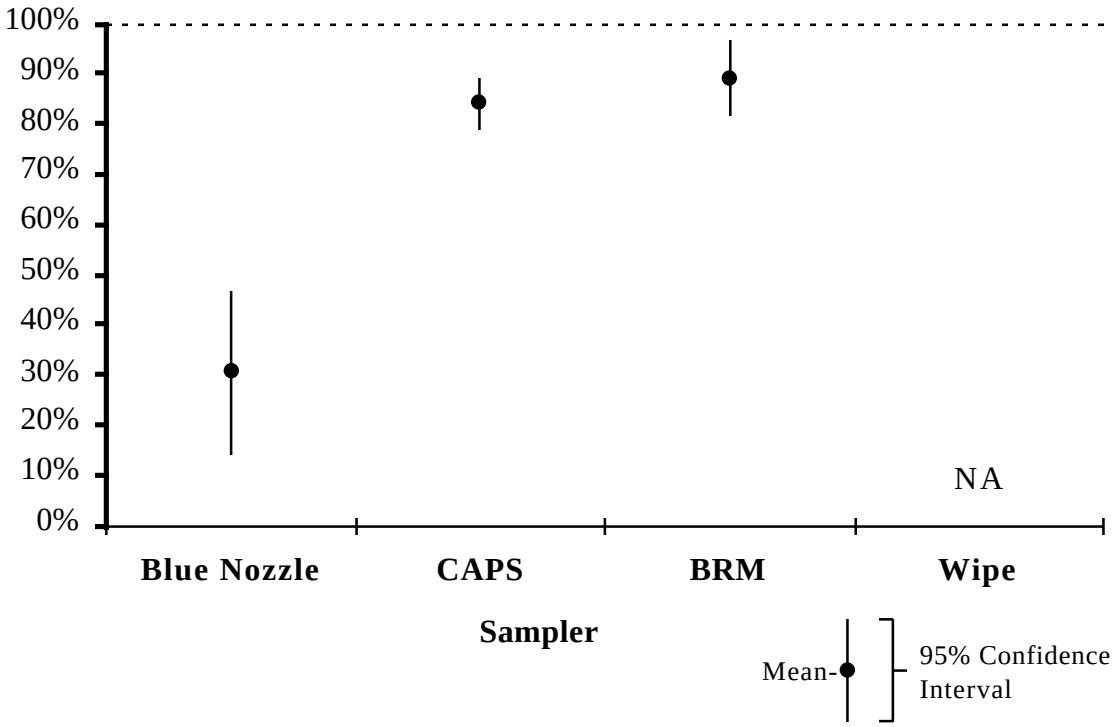


Figure 6-4 Sampler dust recovery by sampler, with 95% confidence intervals, averaged across all substrates

Table 6-3 Average sampler dust recovery by sampler, with 95% confidence intervals

Sampler	Dust recovery	95% confidence interval
Blue Nozzle	30%	14% to 47%
CAPS	84%	79% to 89%
BRM	89%	82% to 96%
Wipe	Not applicable for dust recovery	

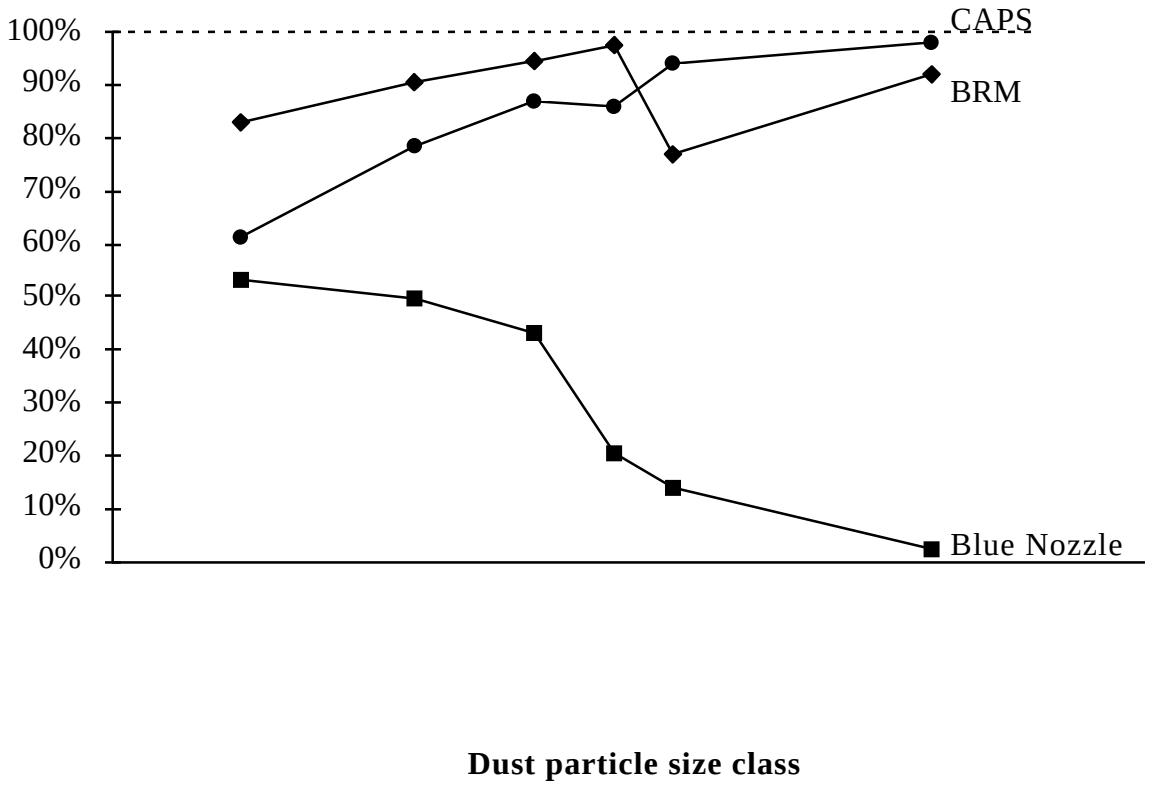


Figure 6-5 Sampler dust recovery by sampler and dust particle size

Table 6-4 Sampler dust recovery by sampler and dust particle size class, with 95% confidence intervals

Sampler	Dust particle size (microns)	lead recovery	95% confidence interval
Blue Nozzle	<53	53%	20% to 86%
	53-106	49%	9% to 90%
	106-150	43%	-14% to 100%
	150-212	21%	-8% to 49%
	212-250	14%	-19% to 47%
	250-2,000	2%	-38% to 43%
CAPS	<53	61%	50% to 72%
	53-106	78%	69% to 88%
	106-150	87%	74% to 101%
	150-212	86%	72% to 99%
	212-250	94%	81% to 107%
	250-2,000	98%	85% to 111%
BRM	<53	83%	69% to 97%
	53-106	91%	78% to 103%
	106-150	94%	70% to 119%
	150-212	98%	84% to 112%
	212-250	77%	63% to 91%
	250-2,000	92%	68% to 116%

The dust recovery differences among different substrates are not statistically significant. Although differences may exist, the differences are small enough that they cannot be adequate assessed from the data. Therefore, the estimated dust recovery for combinations of substrates and samplers is the dust recovery for the sampler used to collect the dust, shown in Table 6-3. Dust recovery could not be determined for the wipe method.

6.3.2 Sampler Lead Recovery

Lead Recovery

The sampler lead recovery is the weight of lead collected by the sampler as a percentage of the weight of the lead deposited on the substrate. The significant predictors of sampler lead recovery are the sampler type ($p < 0.0001$), dust particle size class ($p = 0.0033$), and dust loading ($p = 0.035$). The samplers, in order of decreasing lead recovery, are the BRM, CAPS cyclone, baby wipe, and Blue Nozzle sampler. Lead recovery decreased as the dust particle sizes increased. The measurement standard deviation, pooled across all tests, is 21%.

Figures 6-6, 6-7, and 6-8 and Table 6-5 show the average lead recovery and the associated 95% confidence interval by sampler, dust particle size class, and dust loading. The recovery estimate is shown as a dark circle in the figure. The vertical line through the circle shows the range of the 95% confidence interval on the estimated recovery. Figure 6-6 also shows in gray the predicted average recovery by sampler and dust loading. Figure 6-7 shows in gray the average lead recovery by dust particle size class and sampler. For the smaller dust particle sizes, the lead recovery of the BRM, CAPS cyclone, and Wipe samplers is close to 100%. By contrast, the lead recovery for the Blue Nozzle sampler is significantly lower. The lead recovery estimates for the vacuum samplers include measurements on carpet and upholstery substrates which were not used with the wipe sampling method. Because the substrate is not a significant predictor of sampler lead recovery, wipe recovery can be compared with the lead recovery of the vacuum samplers without having to correct for the different substrates used for different samplers.

The average lead recovery for each sampler (with 95% confidence interval) is 26% (15% to 38%) for the Blue Nozzle sampler, 72% (60% to 84%) for the CAPS cyclone sampler, 81% (70% to 93%) for the BRM sampler, and 63% (43% to 83%) for the wipe sampler. The estimated average lead recovery is the average lead recovery for dust which has equal proportions of dust from each of the six dust particle size classes. In any situation, the lead recovery will vary depending on the relative proportion of dust in each dust particle size class.

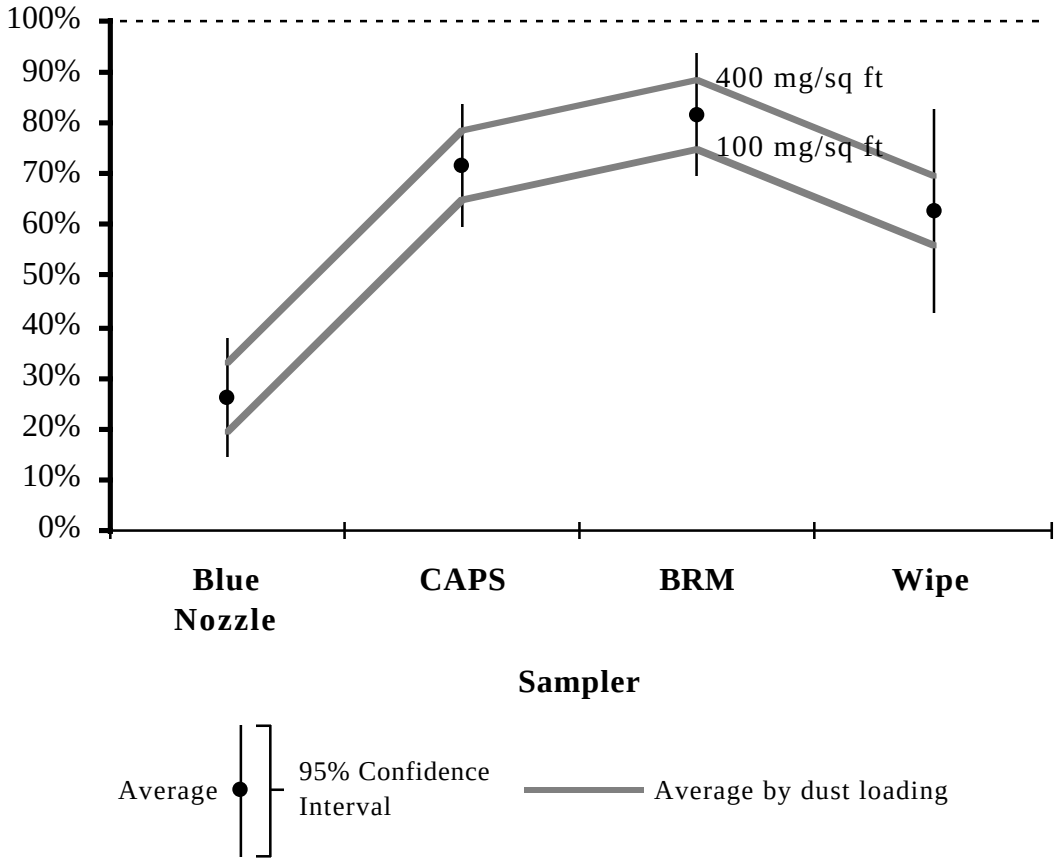


Figure 6-6 Average sampler lead recovery by dust particle size class, with 95% confidence intervals, and by dust particle size class and dust loading

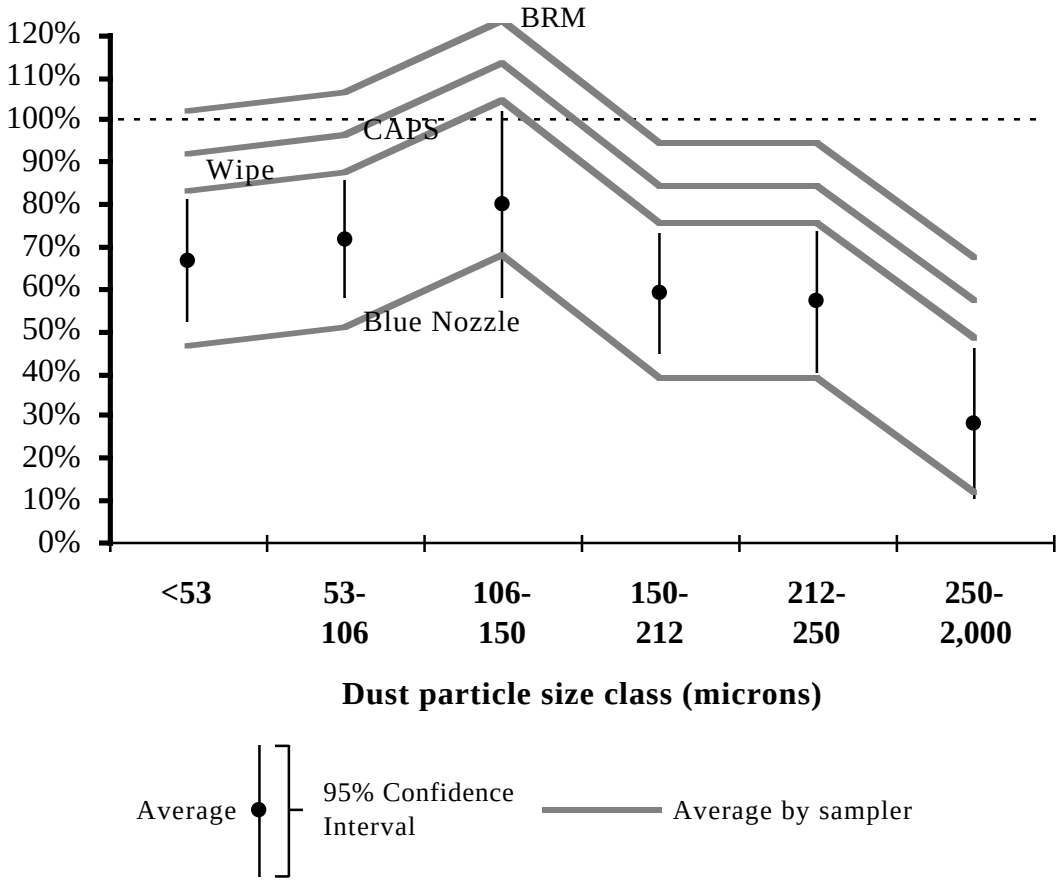


Figure 6-7 Average sampler lead recovery by dust particle size class, with 95% confidence intervals, and by sampler and dust particle size class

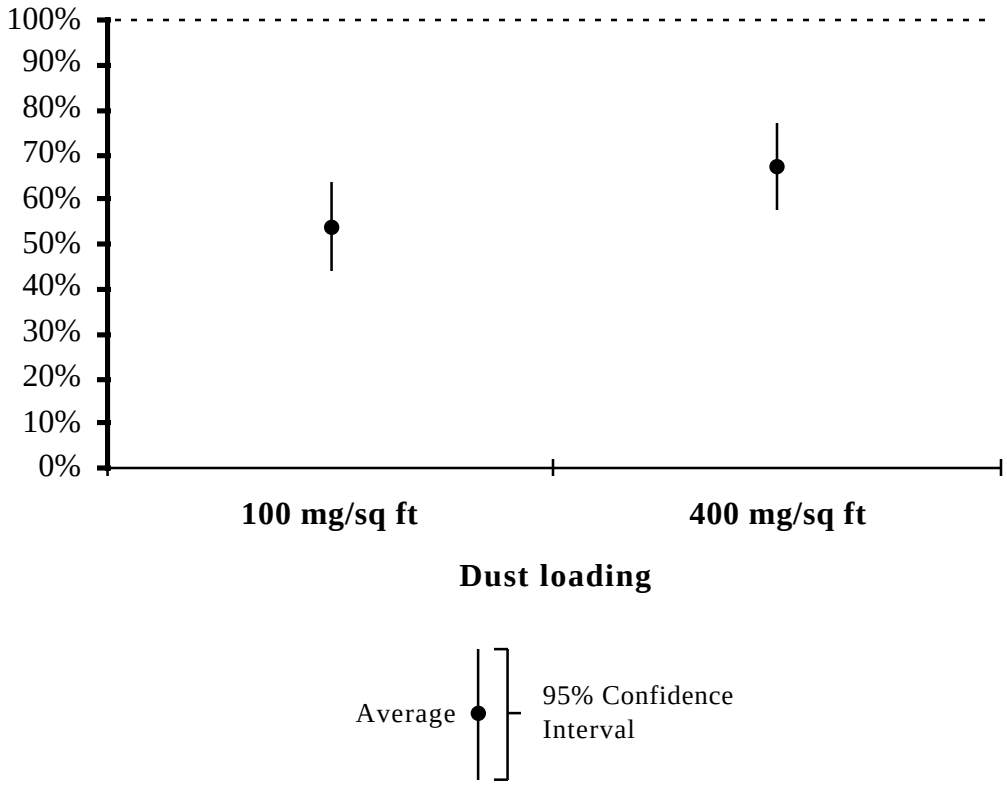


Figure 6-8 Average sampler lead recovery by dust loading, with 95% confidence intervals

Table 6-5 Average sampler lead recovery by sampler, dust particle size class, and dust loading

		Average lead recovery	95% confidence interval
Sampler	Blue Nozzle	26%	15% to 38%
	CAPS	72%	60% to 84%
	BRM	81%	70% to 93%
	Wipe	63%	43% to 83%
Dust particle size	<53	67%	53% to 81%
	53-106	72%	58% to 86%
	106-150	80%	58% to 102%
	150-212	59%	45% to 73%
	212-250	57%	41% to 74%
	250-2,000	28%	10% to 46%
Dust loading	100 mg/sq ft	54%	44% to 64%
	400 mg/sq ft	67%	58% to 77%

The lead recovery differences among substrates are not statistically significant. Although differences may exist, the differences are small enough that they cannot be adequate assessed from the data. Therefore, the estimated lead recovery for combinations of substrates and samplers is the lead recovery for the sampler used to collect the dust, shown in Table 6-5.

Concentration Ratio

The sampler concentration ratio is the ratio of the lead concentration in the dust sample to the lead concentration in the dust deposited on the surface. The ratio depends on one factor which is very significant and several factors which are marginally statistically significant. The most significant predictor of the concentration ratio is the dust particle size class ($p < 0.0001$). The lead concentration ratio is close to 1.0 for the smaller dust particle sizes and decreases as particle size increases. The determination of the significance of other factors depends on the model chosen. Based on the final model, the results suggest that the lead concentration ratio for samplers is lower for the Blue Nozzle sampler than for the BRM and the CAPS sampler. It is also lower for dust from older homes with higher lead concentrations than for dust from newer homes, and higher on carpet and upholstery substrates than on wood, sheet vinyl, and carpets with ground-in dust. The predicted lead concentration ratio averaged across the tests using the three samplers is shown in Figure 6-9 and Table 6-6. The lead concentration ratio cannot be determined for the wipe method.

6.4 Commercial Vacuum Cleaners

The study included sampler tests using each vacuum cleaner, each substrate, and dust from each dust particle size class. However, because not all combinations of these factors were tested, the statistical results are based on mathematical models. The estimates from the models (called least square means) are presented in this section. In the modeling, the effects of dust loading, nominal dust concentration (dust from newer or older homes), operator, substrate, vacuum cleaner, and dust particle size class were tested along with tests of interactions, in particular, differences in vacuum cleaner recovery with different dust particle sizes, and on different substrates. This section discusses the estimates for only those factors which are statistically significant at the 5% level. A more complete discussion of the statistical models is presented in Section 8.

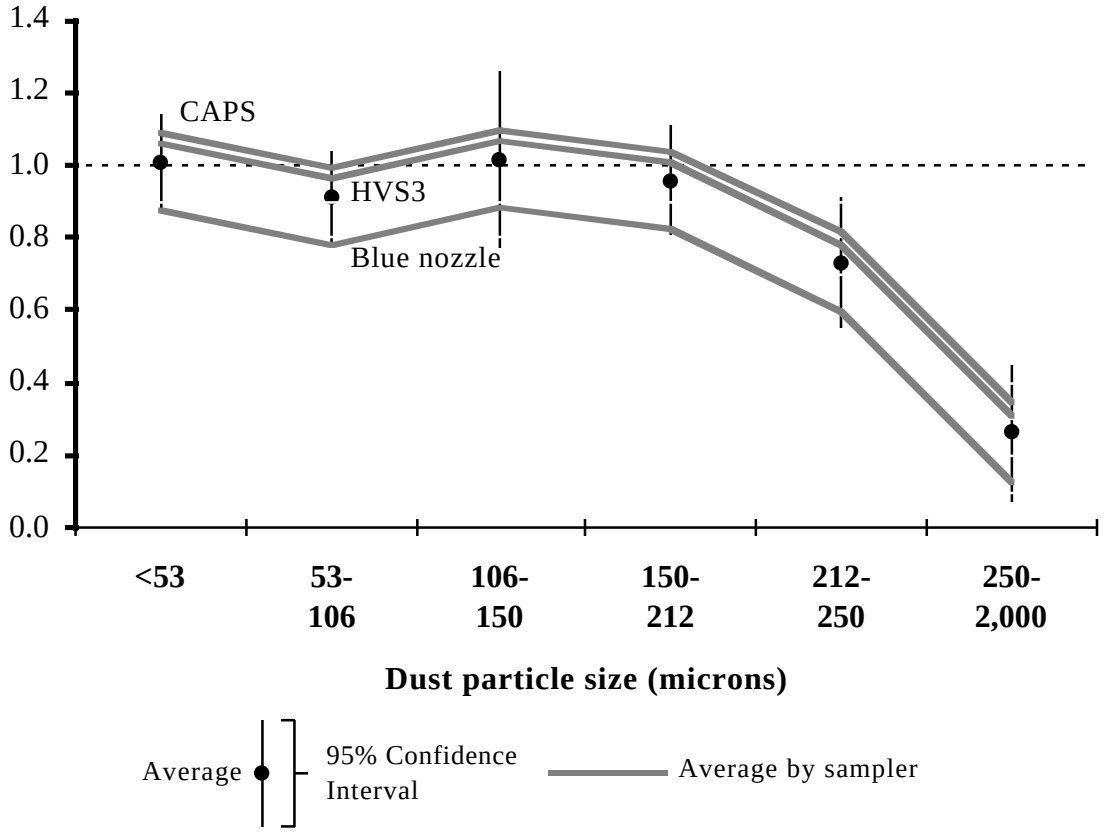


Figure 6-9 Sampler concentration ratio by dust particle size, with 95% confidence interval

Table 6-6 Sampler concentration ratio by dust particle size, with 95% confidence interval

Dust particle size	Average concentration ratio	95% confidence interval
<53	1.01	0.87 to 1.14
53-106	0.91	0.79 to 1.04
106-150	1.01	0.77 to 1.26
150-212	0.96	0.81 to 1.11
212-250	0.73	0.55 to 0.91
250-2,000	0.26	0.70 to 0.45

6.4.1 Dust Recovery

In the vacuum cleaner tests, the substrates were vacuumed for 40 seconds before depositing dust (vacuuming 1). Then dust was deposited on the substrate three times, each time followed by 40 seconds of vacuuming (vacuumings 2, 3, and 4). An additional three vacuumings of 40 seconds each were used to collect residual dust (vacuumings 5, 6, and 7).

For this analysis, the dust recovery for vacuum cleaners is defined as that portion of the dust deposited on the substrate which was subsequently collected in vacuumings 2 through 6. The estimates of dust recovery include a correction for dust from sources other than the dust deposited, such as fibers and carryover dust from other tests. The equation for calculating dust recovery is discussed in Section 8.2.5.

The substrate being vacuumed and the choice of the vacuum cleaner are significant predictors of dust recovery. Figures 6-10 and 6-11 show the predicted average vacuum cleaner dust recovery and the associated 95% confidence interval by substrate and by vacuum cleaner. The recovery estimate is shown as a dark circle in the figures. The vertical line through the circle shows the range of the 95% confidence interval on the estimated recovery. The recovery was highest on wood, upholstery, and vinyl substrates. It was lowest on carpet with ground-in dust and next lowest on the carpet substrate. Differences among vacuum cleaners were small, but significant. The averages and 95% confidence intervals are also shown in Table 6-7.

The dust recovery can also be defined in other ways. Estimates based on the two following alternate definitions of dust recovery are also shown in Figure 6-10:

- The weight of dust collected in all seven vacuumings as a percentage of the weight of dust deposited in the three deposits. This weight approximates the recovery which might be achieved after many more vacuumings.

- The weight of dust collected on the first vacuuming after the first dust deposit (corrected for any fibers or carryover) as a percentage of the weight of the dust deposited in the first deposit.

These estimates represent the extreme recoveries which might be calculated using different definitions of recovery. These high and low estimated average recoveries for each substrate are shown in Figure 6-10 as dashes to the right of the confidence intervals.

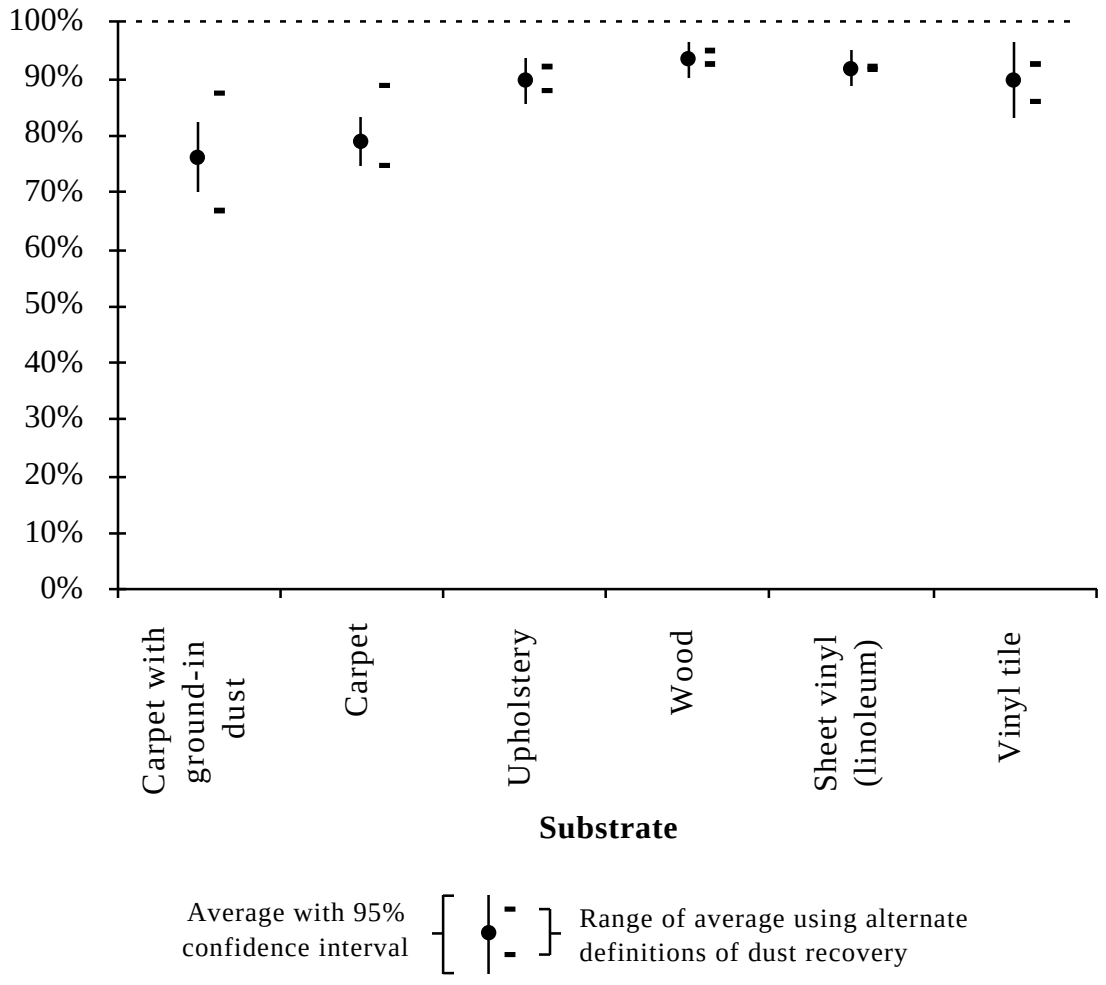


Figure 6-10 Predicted average vacuum cleaner dust recovery for tested substrates with 95% percent confidence intervals and average dust recovery using alternate definitions of dust recovery

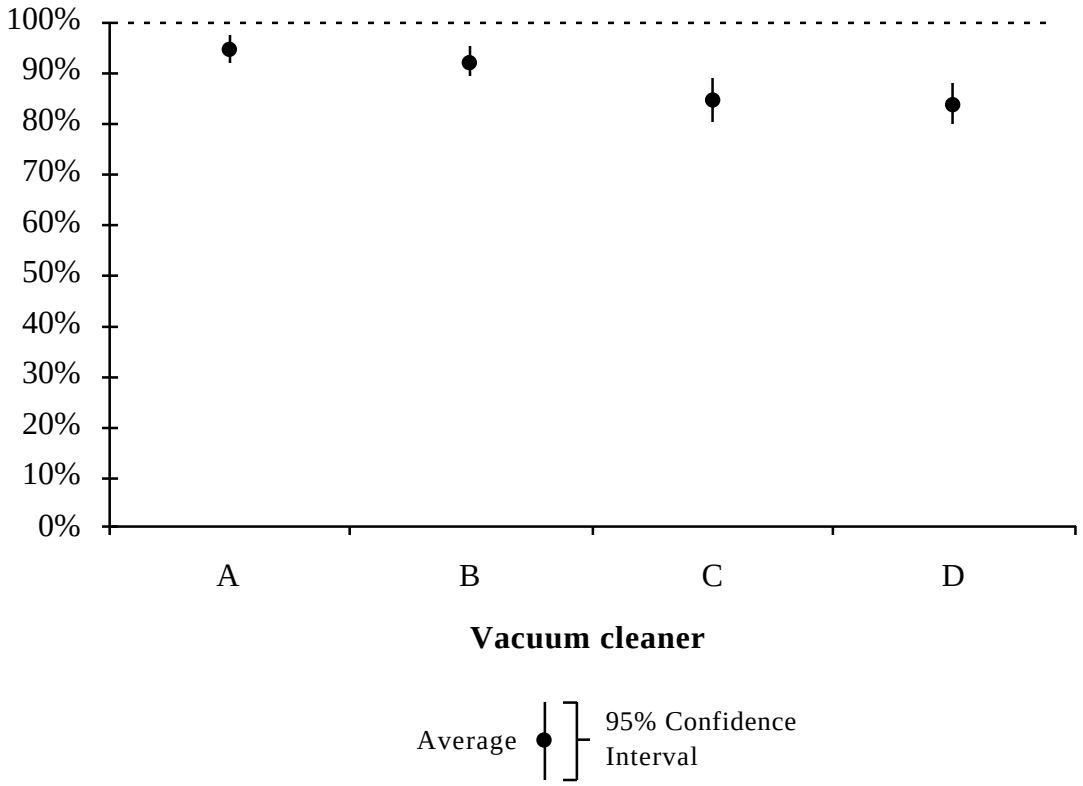


Figure 6-11 Predicted average dust recovery for tested vacuum cleaners with 95% percent confidence intervals

Table 6-7 Predicted average vacuum cleaner dust recovery for tested substrates and vacuum cleaners, with 95% confidence intervals.

	Dust recovery	95 confidence interval
Substrate		
Carpet with ground-in dust	76%	70% to 82%
Carpet	79%	75% to 83%
Upholstery	90%	86% to 94%
Wood	93%	90% to 96%
Sheet vinyl (linoleum)	92%	89% to 95%
Vinyl tile	90%	83% to 97%
Vacuum		
A	95%	92% to 97%
B	92%	89% to 95%
C	85%	80% to 89%
D	84%	80% to 88%

The estimated dust recovery depends on the definition used for recovery. However, the same general pattern of relative recovery among substrates is seen with any of the definitions considered. Regardless of the definition used, at least 5% of the dust is not recovered or accounted for even on the sheet vinyl substrate on which little dust was expected to accumulate. This dust may have been caught in other parts of the vacuum, such as the wand, hose, and other internal parts. However, the study provides no data from which to determine the final destination of the dust not collected in the vacuuming bag. For carpet substrates, a higher proportion of the dust is not recovered and unaccounted for. Experience suggests that some dust may stay in the carpet or pass through the carpet to the floor underneath.

6.4.2 Vacuum Cleaner Lead Recovery

Lead Recovery

In the vacuum cleaner tests, the lead recovery was determined by multiplying the lead concentration in the dust which could be shaken from the vacuum cleaner bag by the weight of the dust recovered and dividing by the weight of lead applied to the substrate. On the average, 26% of the dust collected in the vacuum cleaner bag was removed in this shaking procedure. Because the lead concentration in the vacuum cleaner bag dust may differ from that in the dust shaken from the bag, the lead recovery results for vacuum cleaners must be qualified.

The vacuum cleaner lead recoveries were estimated after correcting for dust removal from the vacuum cleaner bags. The statistical analysis suggests that the observed lead concentration in the dust removed from the vacuum cleaner bag depends on the percentage of dust removed from the bag. The results of this analysis were somewhat inconsistent, suggesting that the effect of dust removal efficiency depended on whether the dust came from newer or older homes. The statistical results provide a correction for different dust removal amounts, such that comparing relative lead recovery among vacuum cleaners or substrates does not depend on the dust removal from the vacuum cleaner bag.

The statistical results do not allow a correction to the overall vacuum cleaner lead recovery estimates for effects associated with dust removal efficiency. The interaction of both (1) vacuum cleaner and substrate and (2) nominal lead concentration (dust from older or newer homes) and percentage of dust removed from the bag were statistically significant. The average vacuum cleaner lead recoveries and associated 95% confidence intervals by vacuum cleaner and substrate are shown in Figure 6-12 and Table 6-8. The lead recoveries by vacuum cleaner and substrate are similar whether or not the dust removal is included in the model. However, the differences are not significant if the dust removal is not in the model.

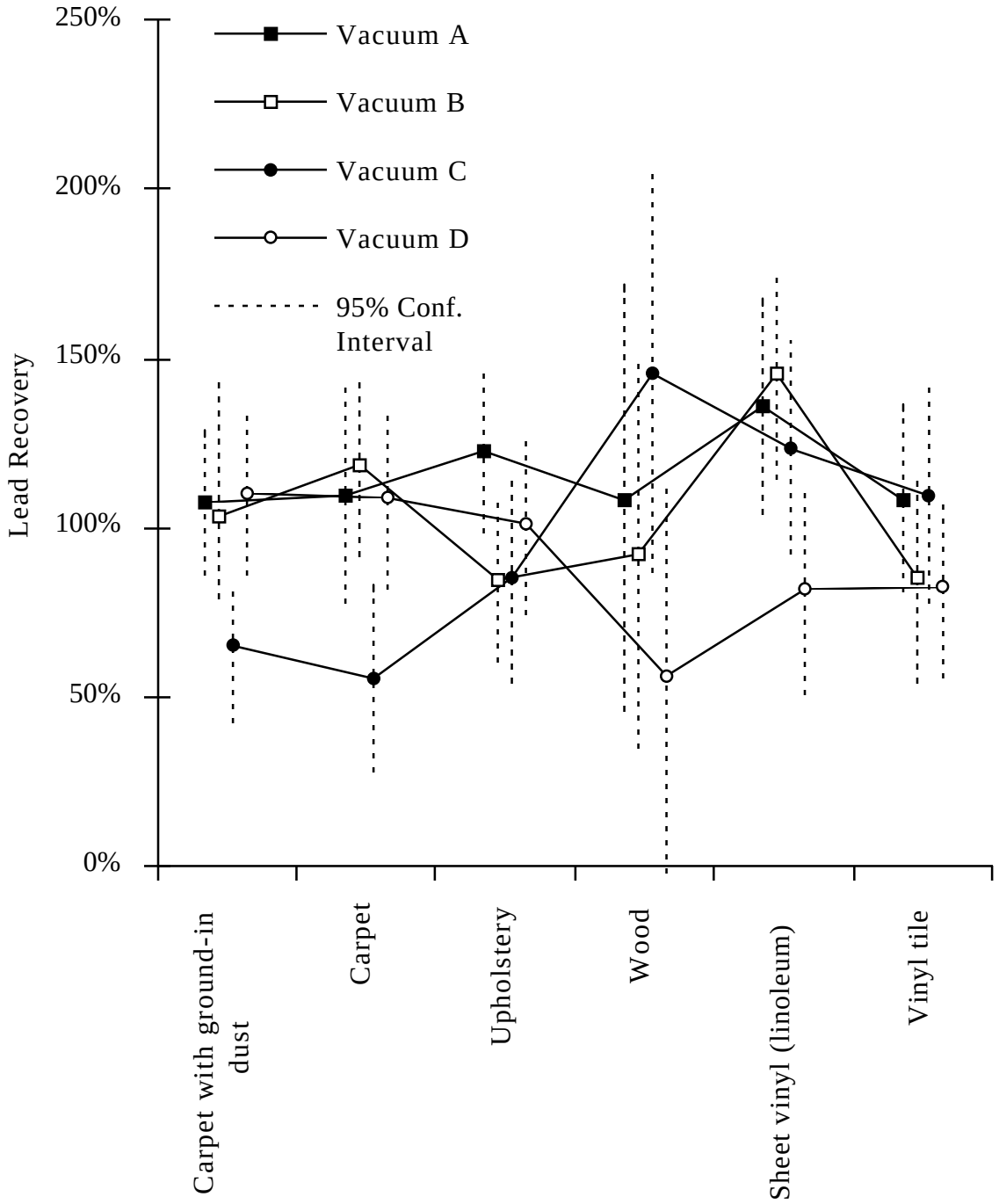


Figure 6-12 Average vacuum cleaner lead recovery by vacuum cleaner and substrate, with 95% confidence intervals

Table 6-8 Average vacuum cleaner lead recovery by vacuum cleaner and substrate, with 95% confidence intervals

Substrate	Vacuum cleaner	Lead recovery	95 confidence interval
Carpet with ground-in dust	A	109%	141% to 78%
	B	119%	146% to 92%
	C	56%	83% to 28%
	D	109%	136% to 82%
Carpet	A	108%	129% to 86%
	B	103%	127% to 79%
	C	65%	87% to 43%
	D	110%	135% to 86%
Upholstery	A	136%	167% to 104%
	B	146%	177% to 115%
	C	124%	155% to 92%
	D	82%	113% to 51%
Wood	A	108%	136% to 81%
	B	86%	117% to 55%
	C	109%	141% to 78%
	D	83%	110% to 56%
Sheet vinyl (linoleum)	A	123%	147% to 98%
	B	85%	109% to 60%
	C	86%	116% to 55%
	D	102%	128% to 75%
Vinyl tile	A	109%	171% to 46%
	B	92%	150% to 35%
	C	146%	204% to 87%
	D	56%	115% to -2%

The average vacuum cleaner lead recovery (after removing two outliers) was 103%, suggesting that more lead was recovered than was deposited on the substrate. A likely explanation for the high lead recovery is higher removal of leaded than non-leaded dust from the vacuum cleaner bag. Thus, the estimated recovery shown in Figure 6-12 may consistently overestimate the actual lead recovery. However, the amount of the overestimation cannot be determined from the study data.

Concentration Ratio

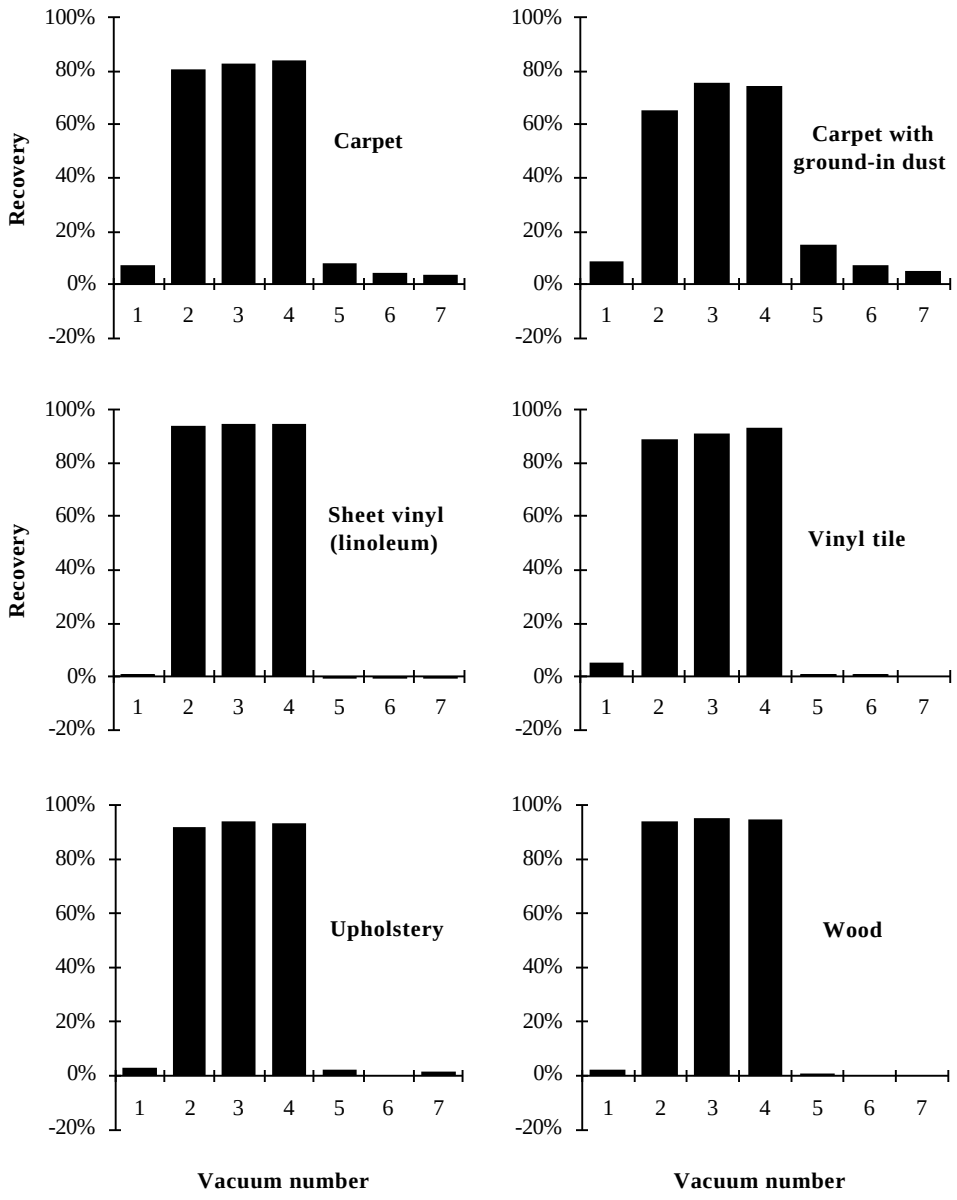
The concentration ratio is the ratio of the lead concentration in the dust removed from the vacuum cleaner bag to the lead concentration in the dust applied. The average concentration ratio across all tests was 1.12. Thus, the measured lead concentration in the vacuum cleaner bag dust was greater than in the dust deposited on the substrate. This result suggests that the lead concentration measurement in the dust removed from vacuum cleaner bags tends to overestimate the lead concentration of floor dust. Since a new bag was used for each test, the relationship between the lead concentration in dust that might be removed from a previously used or partially full vacuum cleaner bag and the lead concentration in the floor dust was not tested in this study.

6.4.3 Effect of Cleaning Effort

The measurements of dust collected for each 40 seconds of vacuuming allow an assessment of the effectiveness of vacuuming for collecting dust as a function of the time spent vacuuming. For each substrate, Figure 6-13 shows the average weight of dust recovered for each of the seven vacuumings which made up the vacuum cleaner tests. The plots in Figure 6-13 are scaled so that the vertical scale measures percent recovery for vacuumings 2, 3, and 4. High recoveries are found for these vacuumings, each of which immediately followed the deposition of dust. The dust recovered in vacuumings 5, 6, and 7 represents what remained on the substrate from previous depositions. The dust collected in vacuuming 1 includes dust from previous tests. For carpets and upholstery, the weight of dust collected includes fibers.

For the sheet vinyl, vinyl tile, and wood, all of which are smooth substrates, essentially all of the dust was collected in the first 40 seconds of vacuuming after the dust deposit. For the upholstery, there is some evidence of a small amount of carryover from the fourth to subsequent vacuumings.

For carpets, the dust recovery for vacuumings 2, 3, and 4 was lower than for other substrates, with a higher recovery for the other vacuumings, indicating dust carryover beyond the first 40 seconds of vacuuming.



Vacuum number
1 = vacuuming before depositing dust
2 = vacuuming after first dust deposit
3 = vacuuming after second dust deposit
4 = first vacuuming after third dust deposit
5 = second vacuuming after third dust deposit
6 = third vacuuming after third dust deposit
7 = fourth vacuuming after third dust deposit

Figure 6-13 Dust recovery versus vacuuming effort for six substrates

6.4.4 Exhaust Emissions

One of the objectives of the pilot study (Task 5) was to determine the amount of dust expelled through the vacuum cleaner bags. The procedures used for this task measured the exhaust emissions from vacuum cleaners by placing five grams of dust on a turntable and feeding the dust into the inlet of each vacuum cleaner at a rate of one gram per minute. Each vacuum cleaner was placed in a sealed enclosure and exhaust emissions from the vacuum cleaners were expelled through the only duct in the enclosure. The dust emissions were measured in $\mu g/m^3$ and recorded on a strip chart recorder. A pitot tube was used to determine the total gas flow rate in the duct, so that the dust emission rate (μg/min) and total emissions (μg) could be calculated.

Exhaust emission levels were calculated from both the strip charts and readings taken at one-minute intervals. For all but vacuum cleaner C, emissions were higher while dust was being injected into the vacuum cleaner than before injection began. The exhaust emission levels peaked generally during the fourth minute of injection. For vacuum cleaner C (with a HEPA filter) the dust concentration in the exhaust was below the ambient level even when dust was being injected. The exhaust emissions from all four vacuum cleaners were lower than expected; an average of 0.01% and at most 0.02% of the dust placed on the turntable was expelled as exhaust. No lead measurements were done for the exhaust emissions because of the time required to collect a sufficient amount of dust from the exhaust for analysis.

In the initial design, two exhaust emissions tests were planned for the pilot study and 12 more were planned for the full study. However, it was determined that all twelve could easily be done in the pilot study, so no exhaust emission tests were performed in the full study. The results from the exhaust emission tests are shown in Table 6-9 and the complete documentation and results of the exhaust emissions tests can be found in Appendix A.

Table 6-9 Average vacuum cleaner exhaust dust concentrations by vacuum cleaner

Vacuum cleaner	Bag	Ambient air levels	Dust expelled (mg/m^3) as exhaust before, during, and after injection			Dust not captured as a percent of dust place on turntable	
			Before	During	After	Dust not captured in the bag	Dust from exhaust emissions
A	1		0.090	0.092	0.065	5.0%	0.020%
A	2		0.057	0.061	0.041	2.4%	0.013%
A	3		0.053	0.037	0.033	2.4%	0.008%
A	4		0.060	0.070	0.051	3.7%	0.015%
B	1	0.004	0.018	0.028	0.015	4.0%	0.006%
B	2	0.009	0.011	0.018	0.011	2.8%	0.004%
B	3	0.006	0.009	0.014	0.010	2.4%	0.003%
C	1	0.004	0.004	0.003	0.003	4.7%	0.001%
C	2	0.013	0.006	0.003	0.003	2.7%	0.001%
C	3	0.012	0.004	0.003	0.003	2.4%	0.001%
D	1	0.012	0.031	0.158	0.020	7.6%	0.021%
D	2	0.017	0.019	0.091	0.015	4.9%	0.011%
D	3	0.012	0.013	0.093	0.013	84.0%	0.012%
Average of the measurements above for each vacuum cleaner							
A			0.065	0.065	0.048	3.4%	0.014%
B		0.006	0.013	0.020	0.012	3.0%	0.005%
C		0.010	0.005	0.003	0.003	3.3%	0.001%
D		0.014	0.021	0.114	0.016	6.3% *	0.015%

*Average excluding the outlier of 84

6.5 Sampling and Measurement Error

Some recovery measurement variation is contributed by variation in the sample collection, sample preparation, and lead analysis procedures. However, most of the variation in the measurements is due to differences among tests using the same dust source and dust particle size class, dust loading, substrate, and sampler or vacuum cleaner. The standard deviation of an individual lead recovery measurement was 21% for the samplers and 27% for the vacuum cleaners. The coefficient of variation (standard deviation divided by the mean) of the lead recovery measurements was 36% for the samplers and 26% for the vacuum cleaner tests. Although there were significant differences between the operators performing the tests in the amount of dust removed from the vacuum cleaner bags for lead analysis, there were no other differences associated with the operators.

There are many possible sources of error including, among others, differences between substrate samples, operators, vacuum cleaner bags, temperature and humidity, and spatial variation in the dust deposited on the substrate. The data from the study can provide no insight as to which of these the possible sources of error might be most important and how the unexplained variation could be reduced.

7 DISCUSSION OF RESULTS

There are currently no standardized laboratory methods to assess how well samplers collect house dust and dust lead or how well household vacuum cleaners clean surfaces contaminated with leaded house dust.[9] The lack of a standardized sampling method necessitated that one be developed for this study.

The final procedure developed for this study used house dust sieved into specified particle size classes. The dust was applied to standard substrates commonly encountered inside a residence. Substrate preconditioning steps were used to ensure that no test was biased from previous tests. The test procedures proved easy to implement and can be easily duplicated by other researchers testing house dust collection devices. By using the same test procedures, a baseline can be established for samplers and various leaded dust evaluation studies can be compared. New collection devices that enter the market can also be quickly evaluated and compared to the baseline.

This section highlights some of the laboratory test results presented in Section 6. Section 7.1 discusses characteristics of the test dust used in this study. Sections 7.2 and 7.3 summarize the results for the samplers and the household vacuum cleaners, respectively. Relationships between these findings and other studies are presented where applicable.

7.1 Test Dust Characteristics

As noted previously, the test dust used in this study was obtained from volunteers who donated vacuum cleaner bags full of normal house dust. Bags were collected from homes within two age groups, older homes built before 1963 and newer homes built after 1982. Dust collected from volunteers whose homes were built between 1963 and 1982 was not used. The dust from homes within each age group was sterilized and then sieved into seven dust particle size classes. The weight of the sieved dust and the dust lead concentration for the six smaller particle size classes used in the study are reported in Section 6.

The findings show that the two groups of house dust, from older and newer homes, contained roughly the same proportion of *total dust*, by weight, in each particle size class. Also, as predicted during the design phase of this study, the dust from the older homes was more lead-contaminated than the dust from the newer homes. The mean dust lead concentrations were roughly 474 μg/ g and 61 μg/ g for the older and newer homes, respectively. However, the distribution of *lead concentration* by particle size

[9]The ASTM has published standard method F609-79 to evaluate the carpet-embedded dirt removal effectiveness of household vacuum cleaners. However, this method uses artificial dust and was not designed to examine cleaning effectiveness on surfaces contaminated with leaded house dust.

class was dramatically different for the two age groups. This result was unexpected and has not been demonstrated by previous studies.

Most studies that have examined lead in house dust by particle size class suggest that lead concentrations in dust increase as particle size decreases. This phenomenon is well documented with numerous references for soil, street dust, and house dust. In the current study, the lead concentration in dust collected from newer homes follows the expected inverse relationship with particle size, but the lead concentrations in dust from the older homes did not exhibit the same relationship. Lead concentrations in the dust from older homes remained relatively stable across particle size classes, except for the largest size class which had the highest lead concentration.

This study and others suggest that the observed differences in lead concentration by particle size for older and newer homes may be explained by two common sources of lead contamination in residential environments, namely lead-contaminated soil and deteriorated lead-based paint. Since houses built after 1982 are unlikely to be painted with lead-based paint, the dust lead in these houses must come from soil, street dust, or other external sources. Since numerous studies show that soil and street dust exhibit the inverse relationship rule for lead and particle size class, it follows that lead in dust from newer homes should exhibit the same inverse relationship. Dust-lead contamination in houses built before 1963 likely results from deteriorated lead-based paint in addition to external sources of lead. If deteriorated paint dust particles are larger and more variable in size than tracked-in or wind blown soil and street dust, then the inverse relationship between lead and particle size may disappear in the dust contaminated by lead-based paint.

The suggestion that higher lead concentrations may be found in larger dust particles and the results from the study that the samplers have lower lead recovery associated with larger dust particles has implications for future studies. If the common belief that finer particles are more adherent to children's hands and more readily absorbed is correct, it may be reasonable to ignore larger particles when sampling. Alternatively, if larger particles contribute significant amounts of lead to children then sampling methods which collect both small and larger dust particles would be preferred.

7.2 Samplers

The performances of one wipe and three vacuum samplers were evaluated in this study. The vacuum samplers were tested for total dust recovery (total dust cannot be measured by wipes) and all samplers were tested for lead recovery. Tests were differentiated by substrate, by the nominal lead concentration of the dust applied to the substrate (high and low lead concentration dust from older and newer homes, respectively), by the dust loading levels (100 and 400 mg/ sq ft.), and by the dust particle size.

The dust recovery is the weight of dust collected by the sampler as a percentage of the dust applied to the substrate before sampling. For the dust recovery tests, the results from the study indicate that the BRM and CAPS cyclone produced the highest recoveries across all substrates and particle size classes. The recovery difference between the two cyclone devices was not significant. The Blue Nozzle sampler had the lowest recoveries, statistically significantly lower than for the cyclone samplers. These results agree with findings from previous studies that indicate that the Blue Nozzle sampler has lower dust recovery than other tested methods. The dust recovery for the Blue Nozzle sampler decreases as the particle size increases. Conversely, the dust recovery for the CAPS cyclone and BRM sampler increases slightly or remains constant as the dust particle size increases.

Sampling precision is a very important factor when sampling house dust. The results from this study suggest that the BRM and the CAPS cyclones are more precise sampling methods than the Blue Nozzle sampler. This is evident in the standard deviations of the dust recovery measurements for the BRM, CAPS, and the Blue Nozzle samplers, which were 9%, 12%, and 29%, respectively.

The samplers, in order of decreasing lead recovery across all substrates and particle size classes, were the BRM, CAPS cyclone, wipe, and Blue Nozzle sampler. The lead recovery of the Blue Nozzle sampler was significantly lower than for the other samplers tested. Average lead recovery across all sampling devices was assessed as a function of particle size class. The lead recovery remains relatively stable for the fine particle sizes and drops off with the largest particle size class. The lead recovery calculation uses the lead concentration measured in the test dust. Any error in the measured lead concentration in the test dust will affect the recovery estimate. The lead concentration measurement for the dust with the largest particle size class has the largest sampling and measurement error. As a result, the apparent drop in lead recovery for dust with the largest particle size class may be due in part to error in the associated dust lead concentration.

The ratio of the lead concentration in the sampled dust to that in the dust applied to the substrate was also examined for the vacuum samplers. When the samplers are pooled, the concentration ratio is close to 1.0 for dust particle sizes less than 212 µm, but drops off sharply with the larger particle sizes. This implies that of the larger particles, the vacuum samplers are selectively collecting a higher percentage of the non-lead particles than of the lead particles.

7.3 Commercial Vacuum Cleaners

Commercially available vacuum cleaners with beater bar attachments were tested for total dust and lead pickup capabilities. The same test dust and substrates used for the samplers were used for the vacuum cleaners. For the vacuum cleaner tests, the dust loading in mg/ sq ft was the same as for samplers, but the size of the test area was larger so that the amount of dust applied was greater.

The dust recovery is the weight of dust collected in the vacuum cleaner bag as a percentage of the dust applied to the substrate during the test. The vacuum cleaner tests involved measurements of the dust collected in seven successive vacuumings of 40 seconds each. Dust was applied to the substrates before the second, third, and fourth vacuuming. Under these test conditions, the dust recovery could be calculated several ways. One such way could be to calculate the weight of dust collected as a percentage of the dust deposited immediately before the vacuuming. This method is most comparable to the definition of recovery used for the samplers. Alternatively, recovery could be defined as the weight of dust collected in all seven vacuumings as a percentage of the dust deposited in the three deposits. This definition would provide higher recovery estimates. For the results presented below, the following intermediate definition of recovery is used: the weight of dust collected in the second through sixth vacuumings as a percentage of the weight deposited in the three dust deposits, after correcting for possible fibers of dust carried over from other tests.

The dust recovery performance of the vacuum cleaners was, as expected, highest for the hard substrates and lowest for carpets. The average recovery ranged from 76% on carpets with ground-in dust to 93% on wood substrates, and the average varied among vacuum cleaners. Differences among vacuum cleaners were small though statistically significant.

Measurement of lead recovery for the vacuum cleaners, which are not designed for making lead measurements, proved difficult. It is not possible to remove all of the dust from the vacuum cleaner bag for testing and it is difficult to measure the lead in the dust without removing the dust from the bag. The procedure used in this study required shaking the dust from the vacuum cleaner bag into a laboratory bottle for subsequent lead analysis. The results can be biased if the dust removed from the bag is not similar in lead concentration to the dust left behind in the bag. The statistical analysis corrected to the extent possible for different amounts of dust removed from the vacuum cleaner bags.

Overall average lead recovery was 103%. However, the vacuum cleaner lead recovery depended on the combination of vacuum cleaner and substrate used in the test. Average recovery for various combinations of vacuum cleaner and substrate ranged from 56% to 146%. The consistent recoveries over 100% suggest that the dust removed from the vacuum cleaner bags may have had higher lead concentrations than dust remaining in the bags, although there is no data from the study to directly support this conclusion. Although the high lead recovery estimates suggest that the true lead recovery for tested vacuum cleaners is high, the amount of bias associated with the test procedures cannot be assessed directly. The CAPS cyclone and BRM samplers both operate in a manner similar to the vacuum cleaners except that the vacuum cleaners had a beater bar and used a filter rather than a cyclone to remove the dust from the airstream. The vacuum cleaner tests involved more effort vacuuming than did the sampler tests. Due to both of these factors, the expected lead recovery for the vacuum cleaners would be greater than that for the BRM and CAPS cyclone vacuum samplers, for which the lead recovery was 81% and 72%, respectively.

The ratio of the lead concentration in the dust removed from the vacuum cleaner bag, to the lead concentration in the dust deposited on the substrate, averaged across all vacuum cleaner tests, is 1.12. In other words, dust from the vacuum cleaner bag provides an estimate of floor dust lead concentrations that is biased by about 12%. This result suggests that procedures which use dust from vacuum cleaner bags to assess possible lead contamination problems will produce lead concentrations which are somewhat higher than the actual concentration in the dust. However, this study only used new vacuum cleaner bags. This conclusion might not apply to full bags.

The analysis of vacuuming effort versus dust recovery (in both the pilot tests and the vacuum cleaner tests) indicates that 80% or more of the dust which has been recently deposited is collected within the first 40 seconds of vacuuming, even when the dust has been ground in. Of the remaining dust, most is collected in the next few minutes of vacuuming. Some dust (at least 5%) may remain in the carpet, upholstery or substrate, or parts of the vacuum cleaner and may not be collected in the bag or otherwise accounted for. With the caveat that not all of the dust deposited on the substrate is accounted for in the data, of the dust collected, almost all is collected in the first 40 seconds of vacuuming.

In the exhaust emissions test originally planned for the study but conducted only in the pilot tests, only 0.01% on average, and at most 0.02%, of the dust collected by the vacuum was emitted in the exhaust. The dust emissions test was performed with dust of the smallest dust particle size class, believed to be the size most likely to pass through the vacuum bag into the exhaust. Based on these tests, the fraction of dust which passed through the vacuum bag is very small. For tests on the vacuum with a HEPA filter, the exhaust had lower dust concentrations than the ambient air.

One question not answered by this study is the extent to which the vacuum cleaner exhaust kicks up dust on the floor and thereby increases the airborne lead concentration. In this study, the vacuum cleaner exhaust may have disturbed some of the dust deposited on the substrates and thus account for some of the dust not otherwise collected in the vacuum cleaner bag. However, the quantity of dust disturbed by the exhaust is likely to be very small because the canister type vacuum cleaners were located on the floor, six inches below the substrate testing surface, and the upright model was well above the substrate surface.

7.4 Effect of Sampling Method on Estimates from the National Survey of Lead-Based Paint in Housing (HUD National Survey)

The dust samples in the HUD National Survey were collected using the Blue Nozzle vacuum sampler. The results were used to estimate the number of priority homes nationally, that is the number of private dwelling units with lead-based paint (LBP), and either non-intact paint or dust loading exceeding the HUD guidelines. Priority housing is further classified as having or not having children under age seven.

The HUD guidelines apply to clearance sampling after renovation and assume that wipe samples are used. The results of this and other studies suggest that the dust and lead recovery of the Blue Nozzle sampler is significantly below that of other samplers, including the wipe sampler. If the wipe or another sampler had been used in the HUD National Survey, how would the number of priority homes change?

The number of priority homes with children under age seven was reported as 3.8 million in the Comprehensive and Workable Plan (CWP).[10] In subsequent revision of the survey results to account for the calibration of the x-ray fluorescence (XRF) equipment and the incomplete sampling of rooms, this number was increased to 4.0 million. See the Report on the National Survey of Lead-Based Paint in Housing, Appendix II, Table 2-8 for details. Using the wipe, BRM, or CAPS cyclone sampler, all with higher recovery than the Blue Nozzle sampler, the estimated number of priority homes with children under seven would be greater than 4.0 million.

Figure 7-1 shows the estimated number of priority homes with children under seven as a function of the recovery of a selected sampler relative to that of the Blue Nozzle sampler. The jagged shape of the curve is due to the discrete nature of survey results. Homes are classified as either having or not having dust over the HUD limits. A home cannot be classified as half over the limit and half under.

The average lead recovery of the Blue Nozzle and wipe samplers is 26% and 63% respectively, and thus the wipe sampler collects about 2.4 times as much lead as does the Blue Nozzle sampler. If we assume that, on all surfaces, the Blue Nozzle sampler consistently recovers 42% of the lead that would be collected using a wipe sampler (i.e. the lead loading for clearance is 2.4 times the measured loading), the revised number of priority homes, determined by analyzing the survey data, would be 4.6 million instead of the 4.0 million based on the Blue Nozzle sampler.

[10]U.S. Department of Housing and Urban Development, Office of Policy Development and Research (1990), Comprehensive and Workable Plan for the Abatement of Lead-Based Paint in Privately owned Housing: Report to Congress.

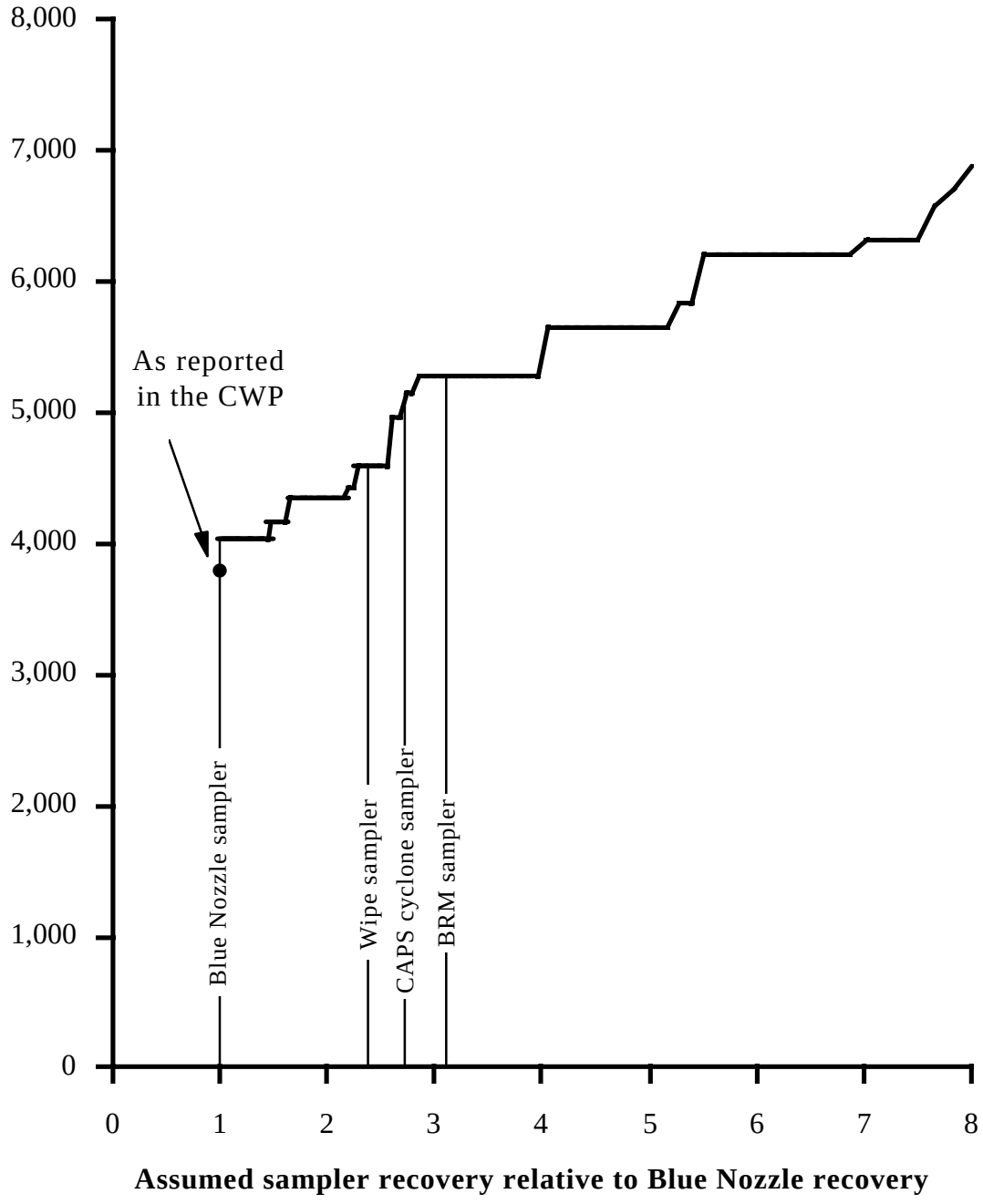


Figure 7-1 Estimated number of priority homes with children under seven as a function of the recovery of other samplers relative to the Blue Nozzle sampler

7.5 Additional Questions

As with most research studies, some questions are left only partially addressed and others are generated as the findings from the study are analyzed. Some original questions that are partially addressed include the relationship of lead and dust recovery to dust particle size in combination with the substrate, sampler or vacuum cleaner. When the study was redesigned due to budget constraints, the number of tests was reduced, limiting the researcher's ability to identify the effect of interactions between dust particle size and substrate or sampler on the lead or dust recovery. In addition, the precision of some of the measurements (particularly lead recovery) was lower than was assumed in the planning stages. Thus, more data collected in a similar manner can be used to provide additional and or more precise information.

The study results have also suggested additional questions which were related to the study objectives but not anticipated in the design. The primary questions involve the location of the dust which was not collected in the vacuum cleaner bag and not seen as carryover from previous tests. Additional information on the location of the dust can be obtained from efforts to collect dust from the vicinity of the substrate, on unvacuumed areas of the substrate, below the substrate for carpet and upholstery substrates, in the air, and in the internal parts of the vacuum. A related question is: would the unaccounted-for dust pose a threat to children? Other questions are: what is the lead concentration in the dust which is easily removed from the vacuum cleaner bags compared to the dust which remains in the bags? How can the lead in vacuum cleaner bags be measured in an unbiased manner?

Still other questions are those which the study was not designed to answer but which are important for addressing the overall objectives of the research effort. These questions are discussed in the following paragraphs.

In dust from homes built before 1963, the lead concentration was found to be similar for all dust particle size classes. This relationship was based on dust composited from vacuum cleaner bags from many homes. Additional studies of dust collected from individual homes can provide information on the extent to which this conclusion can be generalized to all older homes. The relationship between dust particle size and lead concentration may vary among homes depending on the age of the home, presence of children and pets, or other factors. Any differences might affect the risk to young children and, therefore, the choice of sampler for assessing the risk.

EPA has recommended that household vacuum cleaners not be used to clean up lead containing dust after renovation, in part due to concern about small particles passing though the vacuum cleaner bag that then may produce an airborne dust lead hazard. In this study, almost no dust passed through the vacuum cleaner bags, However, only new vacuum cleaners and new bags were tested. Whether the conclusion that very little dust passes through the vacuum cleaner bags can be extended to full vacuum cleaner bags and older models of vacuum cleaners has yet to be determined.

The extent to which the vacuum cleaner exhaust disturbs dust, making it airborne and creating a temporary lead hazard, has yet to be determined. How much dust (and lead) is lifted into the air by the vacuum cleaner exhaust in typical home use? How soon does the airborne dust resettle, and how soon after vacuuming are airborne dust and lead levels safe for children? Of the dust which is not collected by the vacuum cleaner bag, does the vacuuming and/or exhaust cause the residual dust to move to areas which provide an increased or decreased lead risk to children?

Vacuuming, particularly with a new vacuum with a beater bar attachment, may bring dust from deep in the carpet to the carpet surface where it is more easily available to children, thus increasing the lead hazard. Questions to be answered include: under what conditions can vacuuming be effective in reducing the lead hazard? The type and condition of the substrate, type of vacuum cleaner and, for carpets and similar substrates, the amount of accumulated lead will likely affect the answer to this question.

If it can be determined whether and how vacuuming can reduce the lead hazard from floor dust without increasing the hazard from other sources, other questions to answer are: how quickly does dust accumulate? What vacuuming frequency is necessary to control dust and lead loading? How much dust and lead do children ingest from a freshly vacuumed floor, representing the minimum exposure that can be achieved with vacuuming?

7.6 Final Comments

The questions first posed to motivate this evaluation of sampler and vacuum cleaners include:

1. What are the best methods of measuring lead in house dust?

2. What levels of dust lead can be maintained by a typical homeowner using regular vacuuming?

3. Can a homeowner be assured that the vacuuming process does not create an airborne lead hazard? Or, stated another way, how much leaded dust passes through normal household vacuum cleaner bags used over an extended period of time?

Although complete answers to these questions require more research, this study provides the following preliminary answers to these questions.

1. The best methods of measuring lead in house dust vary by the situation and depend on many factors, such as the cost, ease of use, relative recovery, and study objectives. This study provides information only on relative recovery. Overall, the BRM, CAPS, and wipe methods have

similar recoveries and precision. More information is required to determine which method is preferred in any one situation. This study provides some information to help select the preferred sampling method. It is clear, for instance, from this and other studies that the selection of the sampling method does make a difference, with the Blue Nozzle collecting less dust and dust lead than other sampling methods tested. The differences have particular application to interpretation of the results from the HUD National Survey (see Section 7.4) and to the selection of sampling procedures for clearance testing.

2. The results of this study show that a highly rated vacuum cleaner with a beater bar attachment will pick up at least three-quarters of the loose dust present on a variety of surfaces with a moderate vacuuming time. How much more dust is picked up depends on many factors, such as the vacuum cleaner design and whether the dust is ground into the surface.

   The study suggests that lead recovery would be similar to the dust recovery. This study provides no information on how quickly dust accumulates and the levels of dust lead which could be maintained with regular vacuuming. While it is clear that vacuuming removes dust and leaded dust from the vacuumed surfaces, thus reducing the total amount of lead which might pose a risk to young children, it has yet to be determined if routine vacuuming will reduce leaded dust in a way which will result in reduced blood lead levels.

3. This study shows that, for the four vacuums tested (one of which had a HEPA filter) very little dust passes through the vacuum cleaner bag. Further studies are required to determine if this result can be extended to other vacuum designs and to older used vacuum cleaners. Aside from the vacuum cleaner itself, the vacuum cleaner exhaust and the vacuuming process can disturb dust in the room, increasing airborne dust lead levels and possibly creating an airborne lead hazard.

8 DATA PROCESSING AND STATISTICAL ANALYSIS PROCEDURES

This section describes, in detail, the data processing and statistical analysis procedures used to derive the results presented in Section 6.

8.1 Data Entry and Data Processing Procedures

The data was supplied to Westat by MRI on paper and, for the lead analysis results, as text files on computer diskettes. Westat entered the data into computer files, identified outliers or possible errors, and verified the computer files against the original data submissions. Outliers were reviewed by MRI and verified as correct or corrected if possible. As part of the process, Westat had discussions with MRI and visited MRI to make sure the Westat personnel understood the test procedures and how each data element was generated. This helped to assure that the statistical procedures were appropriate for the data. The data entry and verification procedures were different for the gravimetrics (weight measurements) and lead analysis data, as described below.

The first processing step for the gravimetrics data in this study required entering the data onto spreadsheets whose layout was similar to the actual data sheet. Once the data were entered, the spreadsheet files were converted to an ASCII data file and transmitted to EPA's National Computer Center (NCC). A SAS data file was created from the ASCII file and the data were printed in the format of the original data sheets. The printed data sheets were then compared to the original data sheets and any errors were corrected in both the NCC and spreadsheet files. With the corrections in place, the spreadsheets files were again converted into ASCII files and the corrections in both the NCC and newly created ASCII files were reverified. The process of comparing the data in the SAS file to the data on the original sheets checks for both data entry errors and data processing errors. Figure 8-1 shows the processing steps required to prepare the final gravimetric data files.

The text files generated by MRI containing the lead analysis reports were edited to remove introductory text material and then assimilated into one spreadsheet file containing all the lead analysis information. Several variables were combined or modified to make the subsequent analysis simpler. The spreadsheet file was converted to a dBase file and then to a SAS file. The data in the SAS file were then converted to a text file with the same format as the original text file. The text file prepared from the SAS file was electronically compared to the text files generated by MRI. Any errors were corrected in the spreadsheet and SAS files. The corrected SAS file was converted to an ASCII file and sent to NCC where the ASCII file was converted into a SAS file. Figure 8-2 shows the processing steps required to prepare the final data file for the lead analysis data.

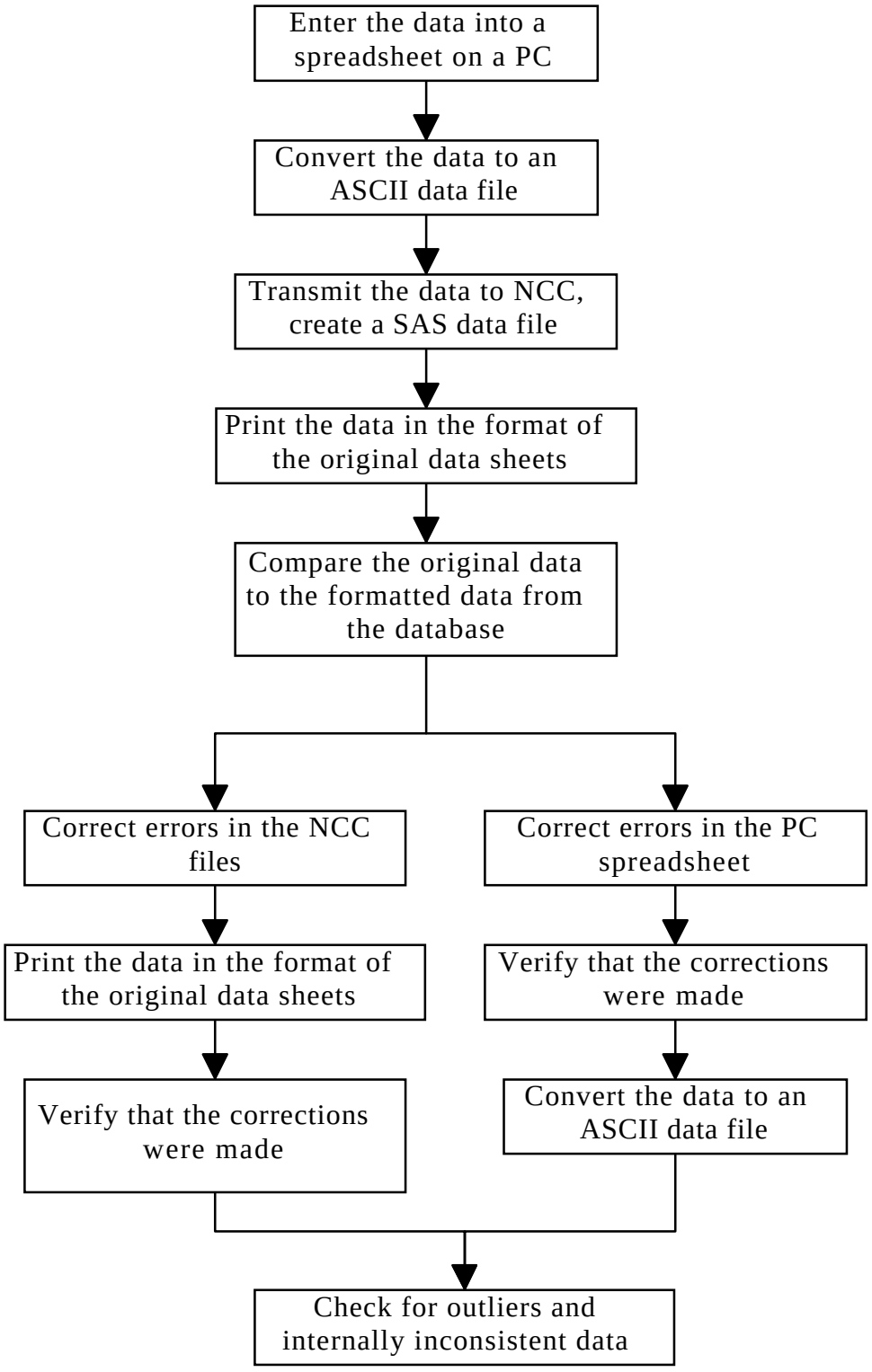


Figure 8-1 Flow chart for data entry and verification of gravimetrics data

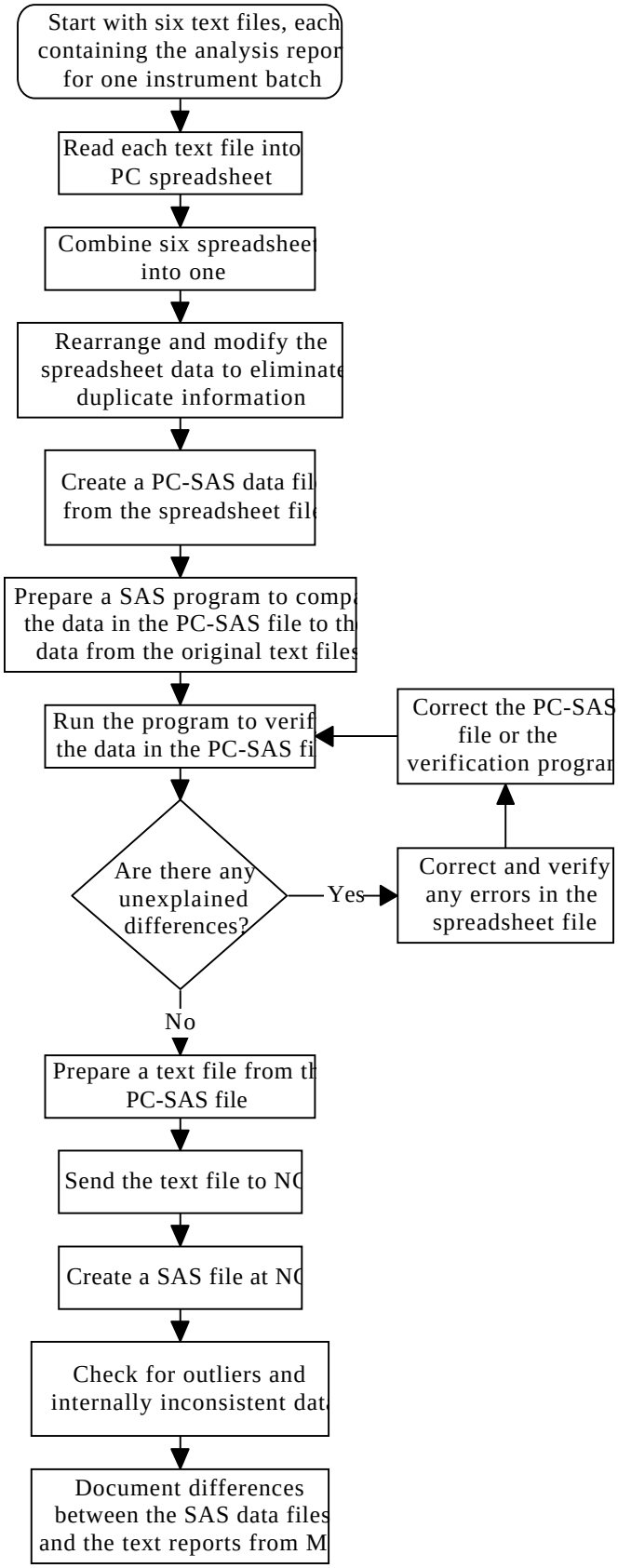


Figure 8-2 Flow chart for data entry and verification of lead analysis data

8.2 Statistical Analysis Procedures

8.2.1 Overview of the Statistical Analysis Procedures

The statistical procedures used to analyze the data were chosen to be appropriate for the purpose of the analysis, the experimental design, and the characteristics of the data. In general, regression models (including analysis of covariance models) were used to analyze the data. The general procedures that formed the basis for most of the analyses are described in this section. The specific statistical procedures used for individual analyses may have differed somewhat from the general procedures, depending on characteristics of the data and the purpose of the analysis. Modifications of the general procedures are discussed in the following sections which discuss individual analyses.

The general approach for fitting a regression model used the following steps:

(1) Starting with the basic model, identify the preliminary model, remove outliers as necessary.

(2) Determine if regression weights are needed to equalize the measurement variance across observations and, if so, calculate the regression weights.

(3) Fit the final model.

(4) Check that observations removed as outliers are outliers based on the final model and regression weights, check residuals for heteroscedasticity, approximate normality, check for serial correlation or other possible problems.

(5) Refit if necessary.

Choosing the model

The original design was designed to estimate main effects for operator, dust loading, nominal dust concentration, dust particle size, substrate, sampler or vacuum cleaner, and interactions between sampler and both substrate and dust particle size. Each combination of dust particle size and substrate shown in Table 4-2 was to be tested using each sampler.

There were four sections of each substrate, one for each combination of dust loading (100 and 400 mg/ sq ft) and nominal lead concentration (low and high, corresponding to dust from newer and older homes). In the experimental design, the same substrate sample was used for all tests using the same combination of dust loading and dust lead concentration. Since independent substrate samples were not used for each test, the

individual tests are nested within the substrate sample. The following paragraphs describe how the analysis reflected this nested design.

The original experimental design was modified as a result of the pilot tests and, after beginning the full study, in response to budget pressures. As a result of the time required to precondition the carpet substrate in the pilot study, the final design was modified to require the same substrate sample for all tests with the same dust loading and dust lead concentration. This modification created a nested design. After the tests for the full study began, it was necessary to cut back on the number of tests to stay within the budget for the project. The redesign of the study was performed quickly and consisted of specifying a fraction of the tests from the original design. In the redesign, the tile substrate was eliminated from further testing, and not all samplers were tested on each combination of substrate and dust particle size shown in Figure 4-15.

The original design assumed a new substrate sample for each test. Due to an oversight, the original design was not modified to reflect the nested design which was adopted as a result of the pilot tests. The incorrect assumption of independent substrate samples was also reflected in the redesign. Thus, the redesign did not reflect the nested design which had actually being adopted. Although the redesign created a roughly balanced experimental design for the main factors and important interactions, these terms were not balanced with respect to the interaction of substrate, dust loading, and nominal dust concentration corresponding to the substrate samples in the nested design. As a result, some of the independent variables in the full model are correlated, resulting in less power than was originally intended. In most cases, the effect of the correlations appears to be small.

In a preliminary analysis, the results of the study were analyzed as a nested design on the assumption that differences between substrate samples were significant. In fact, the analysis results showed that the differences among substrate samples were not close to statistically significant in any of the analyses and that the estimated variance component among substrate samples was often negative. Therefore, for the final analysis presented in this report, the nested nature of the design was assumed to be insignificant and nesting was not included in the statistical model.

The statistical analysis started with a basic model which reflected all the factors in the experimental design. The basic model had terms for:

- A full factorial model of substrate, dust loading, and dust lead concentration (corresponding to the individual substrate samples in the nested design).

- A quadratic model for the log of dust particle size, used to test for non-linear differences associated with the log of the dust particle size.

- An interaction between sampler (or vacuum cleaner) and substrate, the two factors expected to most affect the recovery.

- An interaction between the log of dust particle size and both substrate and sampler (or vacuum cleaner).

- An interaction between the log of dust particle size and nominal dust lead concentration. This term was used only in models for lead recovery and lead concentration ratio for which the recovery depended on the measured lead concentration in the dust. This in turn was a function of the interaction of dust particle size and dust lead concentration.

For the basic model, the logs of 35, 75, 126, 178, 230, and 707 were used to approximate the median particle size in the size classes <53, 53-106, 106-150, 150-212, 212-250, and 250-2,000 microns (μm), respectively. This basic model was applied to the dust recovery, lead recovery, and lead concentration ratio. The lead concentration ratio is the ratio of the lead concentration in the dust removed from the sampler or vacuum cleaner bag to the lead concentration in the dust deposited on the substrate.

Factors that were not statistically significant were eliminated from the basic model in a step-wise (manual) manner to obtain a parsimonious model for the factors which affect the response variable. As the least significant factors were removed, the degrees of freedom for estimating measurement error increased. When there were enough degrees of freedom and, if the terms involving the log of the dust particle size class were close to significant, the continuous variable, log of the dust particle size, was replaced by the dust size class variable. The model obtained after additional stepwise elimination of statistically insignificant factors is referred to as the preliminary model.

As described below, the residuals from the preliminary model were used to determine if there was significant heterogeneity in the measurement variances (heteroscedasticity). If so, regression weights were calculated and used to identify the final model.

Starting with the preliminary model and any regression weights, the final model was identified by considering the effect of changes in the preliminary model on the parameter estimates and p-values. The changes that were considered included adding terms, removing terms, using or not using regression weights, including or removing outliers, and using transformations of the response variables. The objective when identifying the final model was to understand how the assumptions affected the statistical results and to identify one model which reasonably summarized relationships among the data. The presentation of the statistical results includes both a presentation of the final model and a description of how the results are sensitive to the assumptions.

The statistical methods test for differences among the different levels of a factor, such as differences among samplers or dust particle size classes. If significant differences are

found, the pattern of those differences is described in the text. Formal multiple comparison procedures to compare pairs of levels (for example, to compare two samplers) were not performed. Occasionally, in the description of the response patterns, differences are designated as significant based on the following conservative procedure: if two 95% confidence intervals do not overlap, the means are assumed to be significantly different. Similarly, differences are designated as not significant based on the following conservative procedure: if the 95% confidence interval for either mean overlaps the other mean, the means are not significantly different.

Before the design was scaled back, four vacuum cleaner tests were performed using the tile substrate. The small number of measurements on tile provided little information on the correct model for the data. In order to have a more balanced design, the vacuum cleaner tests on tile were excluded from the analysis while identifying the factors in the final model. These tile measurements were then included in order to calculate estimates for the final model. Thus, the model which fit the data from tests using other substrates was assumed to fit the tests using tile.

In some cases, terms were temporarily added to the final model to test for possible carryover (serial correlation associated with either the substrate or the sampler or vacuum cleaner), instrument batch or calibration effects, or other effects. Log and power transformations were considered to normalize the residuals. In most cases, transformations were not needed and therefore not used. Residuals were analyzed to verify that error variance did not vary significantly among classes of observations and that the distribution of the residuals was roughly normal.

Identifying outliers

The extreme studentized residual (ESR) is used to identify residuals which are associated with outlying observations. The extreme studentized residual is the maximum absolute values of the studentized residual. The studentized residual is an optional output from many regression programs. The ESR test assumes that the residuals have a normal distribution. The critical values for the ESR, shown in Table 8-1, depend on the number of observations. They also depend on the model used to obtain the residuals and the criteria for defining the significance level for the test. The values in Table 8-1 are appropriate when fitting just a mean. Consideration of additional factors in the model would have slightly decreased the critical values shown in Table 8-1. Therefore, use of the values in Table 8-1 represents a conservative test; the true probability of deciding that the most extreme observation is an outlier is less than the nominal 5%. For numbers of observations not shown in Table 8-1, interpolation was used.

Table 8-1 Critical values for the extreme studentized residual (5% level)[11]

Number of observations	Critical value
20	2.777
24	2.861
30	2.958
35	3.02 [a]
40	3.08 [a]
60	3.23 [a]
120	3.47 [a]
240	3.67 [a]
480	3.86 [a]
960	4.03 [a]

[a]Approximate values predicted, using nonlinear regression, from theoretical values based on a normal distribution with known mean and standard deviation.

[11]For a mean model, the extreme studentized residual (ESR) has the following relationship to the extreme studentized deviate (ESD) and the maximum normed residual (MNR):

$$ESR = ESD \sqrt{\frac{n}{n-1}} = MNR \sqrt{n}$$

Critical values for the maximum normed residual are presented in Snedecor, G. W., and Cochran, W. G., 1980. *Statistical Methods,* Seventh Edition, Iowa University Press, Ames, Iowa

Outliers were removed from the analysis in order to identify the final model. They were then included to determine if, based on the final model, they would still be classified as outliers.

Determining regression weights

Regression methods assume that the errors, after applying any regression weights, have constant variance across all observations. Appropriate regression weights improve the estimates and their confidence intervals. These weights are proportional to the inverse of the error variance, in this case, the sampling variance plus measurement variance.

One method for identifying classes of observations that have different variance, suggested by Levene,[12] uses analysis of variance or regression on the absolute values of the model residuals. In this study, a modification and refinement of this basic approach was used. Regression analysis was performed on the following function of the studentized residuals:

$$V_i = \ln(0.05 + r_i^2)$$

where r_i is the studentized residual for the i^{th} observation i. The square of the studentized residual has a chi-squared distribution with one degree of freedom assuming constant variance. The constant 0.05 makes the log transformed values approximately normally distributed. This constant is generally small relative to r_i^2 which has a mean of 1.0. The standard deviation of V is roughly constant even when heteroscedasticity exists. A regression model, referred to as the variance model, with terms for the main effects, is then fit to V. To account for the fact that the studentized residuals are not independent, weighted regression, using regression weights equal to $1-h_i$, was used to fit the variance model, where h_i is the diagonal element of the hat matrix and $1-h_i$ is proportional to the variance of the residual. The values h_i are an optional output from many regression programs. In addition, for testing significance of factors in the variance model, the residual degrees of freedom for error in the variance model is the error degrees of freedom from the preliminary model minus the number of parameters fit to V. Note that the sum of $(1-h_i)$ is the error degrees of freedom from the preliminary model. Simulations indicate that this approach performs well in maintaining the false positive rate under constant variance and reasonable power to detect differences in variance when they exist. This procedure for calculating regression weights has the advantage that it is relatively simple, can be used for complex models, and provides reasonable estimates of the regression weights.

[12]Levene, H. 1960. In *Contributions to Probability and Statistics.* Stanford Univ. Press, Stanford, Calif., p. 278

Because the regression weights need only be proportional to the inverse of the error variance, the predicted values (Pred(V)) from the regression on V can be used to calculate regression weights (Wgt) for the final model using the following formulas:

$$Wtemp = 1/(\exp(Pred(V)) - 0.05).$$

$$Wgt = Wtemp/Mean(Wtemp).$$

These weights are standardized for convenience so that the sum of the weights equals the number of observations. A second iteration can be used to refine the weights by using the residuals from the weighted regression to calculate a second set of weights which are multiplied by the first. These refined weights, when calculated, were also standardized.

The following steps were used to test for non-constant measurement variance:

(1) Save the studentized residuals and h_i (the diagonal of the hat matrix) from the preliminary regression.

(2) Calculate V and the regression weights for the variance model.

(3) Fit a parsimonious model to V to test for non-constant variance, assuming that the possible factors in the variance model are the same factors as in the preliminary model. Sometimes other factors were also considered.

(4) If the overall F statistic for the variance model is significant (based on the adjusted error degrees of freedom), assume that heteroscedasticity exists, save the predicted values, and calculate the regression weights for the final model.

A parsimonious model for variance is required because the degrees of freedom for estimating variance effects is reduced by the model degrees of freedom in the model from which the residuals were obtained. There may not be many degrees of freedom left to fit a complicated model. A parsimonious model is also reasonable compared to the generally accepted procedure of assuming constant measurement variance.

A note on the results

The theoretical values for the recovery range from 0% to 100%. Some confidence intervals, as well as some of the measurements, extend beyond the theoretical limits of 0% and 100% recovery. The measurements can be outside this range due to variation in the testing and measurement process. The confidence intervals apply to the true mean for the measurement process and not to the true mean for the actual process. Although the recovery estimates should be unbiased in a statistical sense, and the confidence intervals should fall within the 0% to 100% range as more data is collected, some

readers may be uncomfortable with estimates which appear to be illogical. That the interval exceeds 100% does not indicate that an incorrect method was used to calculate the confidence interval. Significant effort, possibly including simulations, would be required to calculate and justify alternate confidence intervals which are restricted to the range of 0% to 100%. For that reason, the modeling was not performed.

8.2.2 Statistical Analysis of Sieved Dust Lead Concentration

The dust in this study came from donated vacuum cleaner bags which were used in either older homes, built before 1963, or newer homes, built after 1982. The dust from the vacuum cleaner bags was removed and sieved into the following six particle size classes: less than 53 μm, 53 to 106 μm, 106 to 150 μm, 150 to 212 μm, 212 to 250 μm, and 250 to 2,000 μm. Particles with sizes greater than 2,000 μm were discarded. Dust from homes in the same age class and in the same particle size class was physically mixed and placed in a plastic bag.

Before the study began, duplicate grab samples of dust were selected from each bag of dust after mixing the dust and were then analyzed for lead. As the study progressed, samples of dust were collected periodically to measure the lead concentration in the dust actually deposited onto the substrates and to determine if the concentration changed over time due to settling or stratification in the bags of dust.

As described below, a weighted analysis was used to analyze this data because a preliminary analysis suggested that the variance of the measurements varied considerably among dust particle size classes. The variance of lead concentration measurements can be estimated either from the data or by using a theoretical model. The theoretical model provides insight into the expected patterns of variance as a function of dust particle size and was used to calculate the regression weights for analysis of the dust data. The following discussion describes the assumption behind the theoretical model.

The dust particles are assumed to be of two types, leaded particles which have lead associated with some non-lead material and non-leaded particles which contain no lead. Within a dust particle size class, the dust particles are assumed to be the same size. The lead concentration in the leaded particles is assumed to be the same for all such particles. The process of sampling dust for analysis is assumed to be a random selection of dust particles, some with lead and some without. Each type of particle is assumed to have the same chance of selection. The number of particles in a sample can be determined from the weight of the dust compared to the average weight of a dust particle. The proportion of the leaded particles in the sample will have a binomial distribution. The lead concentration in the dust sample will depend on the number of leaded particles and the amount of lead in each particle. The relative variance of the lead concentration in the dust sample can be determined from the binomial relative variance. These relationships are described in more detail in the following equations.

If the weight of lead in the leaded particles is assumed to be R times the weight of the non-lead particles and the proportion (P) of leaded particles is small, then P is approximately:

$$P = C / (R * 1{,}000{,}000\ (\mu g/g))$$

where C is the lead concentration (µg/ g) in the dust sample. For these calculations, R is assumed to be one-half, that is, the weight of lead in the leaded particles are assumed to be half the weight of the non-lead particles. Because the density of lead is much greater than 1.5 times the density of most dust components, setting R = 0.5 is equivalent to assuming that the lead is associated with paint constituents or other relatively light material.

The relative variance (square of the coefficient of variation) of P is:

$$Relvar(P) = (1-P) / (nP)$$

where n is the number of particles in the sample to be analyzed in the lab. The number of particles in the sample is the weight of the sample divided by the weight of a particle, which is the volume of the particle multiplied by the density. The volume (V) of a spherical particle in cubic centimeters is:

$$V = [0.81\ d / (10{,}000)]^3$$

where d is the diameter in microns. The assumed diameter of the particles is 35, 75, 126, 178, 230, 707 for the particle size classes <53, 53 to 106, 106 to 150, 150 to 212, 212 to 250, and 250 to 2,000 microns, respectively. These diameters are approximately the geometric mean between the largest and smallest size within the size class.

Assuming that the density of the dust particles is 1.0 gm/ cc (the density of water), the number of particles in the sample is:

$$n = Wt / V$$

where Wt is the weight of the sample in grams. The estimated number of dust particles is greater than 3,500 for all of the sieved dust samples. With this number of particles, very little of the variation in the weight of the dust collected is associated with the particle size.

When analyzing the natural log of the lead concentration measurements, the regression weights should be roughly proportional to the inverse of the relative variance of the measurements. The relative variance of the measurements is equal to the sum of the relative variance due to sampling and the relative variances due to preparation and measurement. In the following formula for the regression weights (Wgt), the relative variance associated with preparation and measurement is based on the analysis of precision presented in Section 8.2.6.

$$Wgt = \frac{1}{\left(\frac{1-P}{nP}\right) + \left(0.0183 + \frac{0.0184}{InstResp}\right)^2 + (0.0376)^2}$$

In this formula, InstResp is the ICP instrument response. All sieved dust samples were analyzed using ICP.

One outlier was identified in the preliminary analysis. Based on the final regression weights, this outlier was 4.55 standard deviations from the mean (test number 641, using the smallest dust particle size). The outlier was removed when calculating the geometric means and the final regression weights.

The regression weights range from .18 to 460. The ratio of the largest to smallest weight is 2,557 to 1. The wide range in the regression weights suggests that the variance of the lead concentrations varies considerably among dust samples of different dust particle size classes and different lead concentrations.

Figure 8-3 shows the relative variance, expressed as a coefficient of variation (CV), as predicted by the model for the regression weights, of the lead measurements for each dust bag, averaged across all bags. According to the model, the measurements for the coarse dust samples are much more variable than for other dust samples. Similar results may apply to the lead recovery measurements from the sampler and vacuum cleaner recovery tests. Figure 8-3 also shows the coefficient of variation for the measurements from each bag of dust. In general, the observed CV's are close to those predicted by the model.

These regression weights were used to fit a model and estimate the geometric mean lead concentration for each bag of dust (one for each dust particle size class and age of house) and the associated confidence interval, and to determine if there was a trend in the lead concentrations over time.

If the assumptions used to calculate the regression weights and remove outliers are correct, the mean square error in the final model would be 1.0. The mean square error for the final model is 1.09. This value is very close to 1.0 considering the approximations which were used to derive the regression weights, and it indicates that the relative variance from the model may slight underestimate the true relative variance for the data. Since the confidence intervals will be correct if the relative regression weights are correct, even if the regression weights are consistently biased, the regression weights appear to provide a reasonable basis for calculating the confidence intervals.

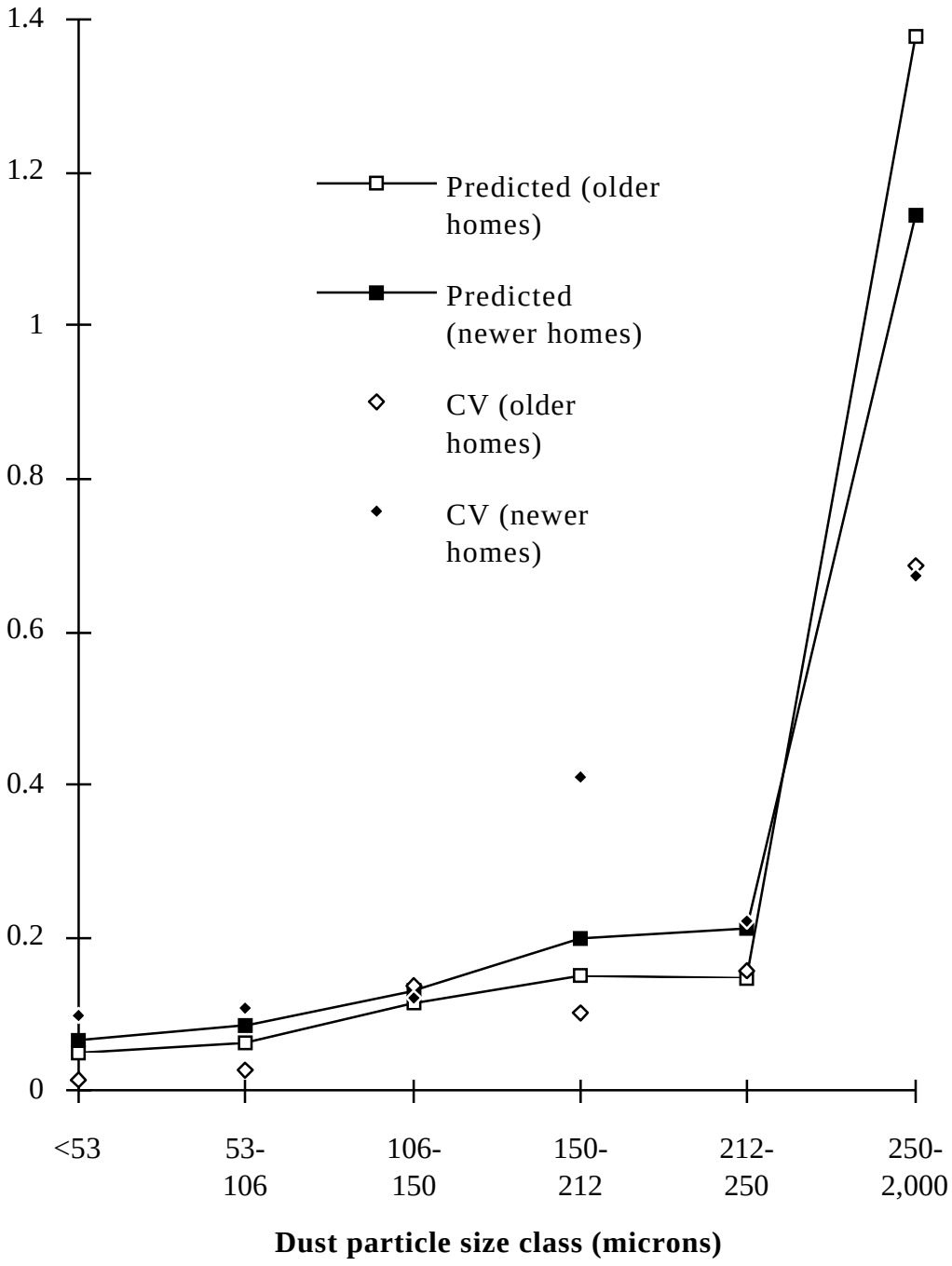


Figure 8-3 Relative standard deviation of lead concentration measurements for sieved dust by dust particle size class and age of home, as predicted by the theoretical model

The lead concentration was modeled as a function of time (days since the first samples were taken on September 17, 1993) using regression. The weighted analysis showed that the trend in the lead concentration with time varied significantly among bags of dust ($p=0.016$). Therefore, a separate regression was fit to the data from each bag. The slopes generally increase slightly, with the greatest increase in concentration over time in the dust with the largest particle size class. Changes in the dust characteristics can occur if handling of the dust bags causes the lead particles to separate slightly from the non-lead particles. For example, if the lead particles tend to move on top of the non-lead particles, the lead concentration at the top of the bag, where the dust is removed for the tests, may have a higher lead concentration than samples taken from the bottom of the bag. The equation for the lead concentration was used to predict the geometric mean concentration of lead in the dust used in the tests, which was used to calculate lead recovery.

Statistical tests were performed to determine if the measured lead concentration differed between the initial grab samples and the subsequent samples in which the dust sample was collected by passing the dust through a sieve, as in the recovery tests. No differences in the lead concentration were found from the way the sample was collected. Statistical tests were also performed to test for differences between preparation or instrument batches. These terms were not significant. Tests for homogeneity of variance were just significant at the 5% level, suggesting that the regression weights did not completely model the variance of the measurements. However, there was no apparent pattern in the variances which would indicate a possible change to the model. The dust lead concentrations by dust particle size class for dust from new and old homes are presented and discussed in Section 6.2.

8.2.3 Statistical Analysis of Gravimetric and Lead Analysis Data for Samplers

The sampler tests involved depositing a known amount of dust over a one square foot area of the substrate, using the sampler to recover the dust following standard protocols for each sampler, and determining the weight of dust recovered (gravimetric data) and amount of lead recovered. These measurements were used to calculate the dust recovery, the lead recovery, and the ratio of the lead concentration in the dust collected by the sampler to the lead concentration in the dust deposited on the substrate. Four samplers were studied, the CAPS cyclone, BRM, Blue Nozzle samplers, and baby wipes. The wipes were not tested on upholstery, carpet, or carpet with ground-in dust. Total dust recovery was also not measured for the wipes.

A procedural error was made on one test (3-12). This test was repeated as test 3-25. The data for test 3-12 would be considered outliers and were not used in the analysis.

Gravimetric Data

The sampler dust recovery is the weight of dust collected by the sampler as a percentage of the weight of dust deposited on the substrate. In the final model for sampler dust recovery, the sampler type was a highly significant predictor of sampler dust recovery ($p < 0.0001$).[13] The combination of sampler type and dust particle size was significant ($p = 0.038$). An analysis of the residuals showed that the measurement variance was significantly related to the sampler type ($p = 0.029$) and, therefore, a weighted analysis was used. Similar results were obtained when regression weights were not used and when transformations were considered. Whether one observation (test 4-23) could be considered to be an outlier depended on the weights used. No observations were excluded from the final analysis. The term for an interaction of sampler and substrate was not close to statistically significant. The dust recovery estimates for samplers are discussed in Section 6.3.1.

The half-width of the confidence intervals for the average dust recovery for the Blue Nozzle, BRM, and CAPS cyclone sampling methods are 16%, 7%, and 5%, respectively. Except for the Blue Nozzle sampler, these confidence intervals meet the data quality objectives of 8% for these estimates. The confidence interval half-width for dust recovery using a selected sampler and substrate, averaged across substrates, ranges from 15% for the CAPS, to 20% for the BRM sampler, and 45% for the Blue Nozzle sampler. Of these half-widths, only the value for the CAPS meets the data quality objective of 15%. The standard deviation of the dust recovery measurements for the Blue Nozzle, BRM, and CAPS cyclone samplers are 28%, 12%, and 9%, respectively.

An additional data quality objective of ±30% for recoveries for a combination of substrate, sampler and dust particle size (corresponding to individual measurements, if made) is met by the CAPS cyclone and BRM samplers but not by the Blue Nozzle sampler. Most of the data quality objectives were achieved for the BRM and CAPS cyclone samplers. The dust recovery measurements for the Blue Nozzle sampler were more variable than for the other samplers, in part due to the low recovery. Therefore, the Blue Nozzle sampler did not achieve any of the data quality objectives. Note that the number of sampler tests was determined from the precision of the dust recovery measurements for vacuum cleaners. No corresponding precision data from which to estimate sample size were available for the samplers.

Lead Data

For one test (test 4-4, using the Blue Nozzle sampler on carpet), a comment on the data sheet indicates that the reported lead measurement may be low by 8% due to over-dilution. Thus, the data for this sample was used in the statistical analysis after increasing the lead amount and lead concentration by 8%.

[13] p-values indicate the probability that differences as large as those observed could be due to chance alone. Generally, p-values less than 0.05 indicate statistical significance.

Measurements from two of the 51 sampler tests were identified as outliers and were removed from the analysis. These tests are summarized in the following table. The ESR values indicate the number of standard deviations separating the observation from its expected value after excluding more extreme outliers. After removing these outliers, there were 49 measurements for the analysis.

Test No.	Sampler	Substrate	Lead recovery	Dust recovery	Concentration ratio
3-13	CAPS	Linoleum	2.36 (ESR = 3.65)	0.87	2.72
4-1	Wipe	Linoleum	2.05 (ESR = 3.52)	NA	NA

The lead recovery is calculated as the weight of lead in the sample divided by the weight of dust deposited on the substrate and by the lead concentration in the dust.

The statistically significant terms in the final model for the lead recovery are the sampler ($p < 0.0001$), dust loading ($p = 0.035$), and dust particle size ($p = 0.0033$). The significance level of the interaction of sampler and substrate depended on whether weights were used. An analysis of the residuals suggested that the measurement variance was related to the interaction of dust loading and nominal dust concentration, but the significance of variance differences also depended on the model used. Because the pattern of the observed variances by dust loading and nominal dust concentration was difficult to interpret based on physical considerations, the final model did not use regression weights. In an analysis of transformed data, using ln(Dust Recovery + 0.5), only the sampler type and dust particle size class were statistically significant. It was decided not to include terms for the interaction of sampler and substrate in the final model. With the outliers included in the final model, the dust loading is not statistically significant. The measurement standard deviation is 21%. The sampler lead recovery estimates are presented in Section 6.3.2.

Concentration Ratio

The concentration ratio is the ratio of the lead concentration in the dust sample collected by the sampler to the lead concentration in the dust deposited on the surface.

Three of the 42 observations were removed for the analysis as outliers. The studentized residuals were estimated using a model with the one factor, sampler type, which was statistically significant in all regressions. The following table describes the outliers which were removed from the analysis. The ESR values in the following table indicate the number of standard deviations separating the observation from its expected value after excluding more extreme outliers.

Test No.	Sampler	Substrate	Lead recovery	Dust recovery	Concentration ratio
3-13	CAPS	Linoleum	2.36	0.87	2.72 (ESR = 3.32)
4-2	Blue Nozzle	Carpet	0.11	0.04	2.44 (ESR = 3.76)
4-7	BRM	Carpet	1.31	0.66	1.99 (ESR = 4.07)

The concentration ratio appears to depend on many marginally statistically significant factors. In the final model, the significant factors for predicting the sampler concentration ratio are: dust particle size ($p < 0.0001$), sampler ($p = 0.0193$), nominal lead concentration ($p = 0.0368$), and substrate ($p = 0.0476$). The most significant predictor of the concentration ratio is the dust size. The determination of the significance of other factors depends on the terms chosen for the model. No regression weights were needed or used to equalize the measurement error. If the three outliers discussed above are included in the model, and insignificant terms are removed, the only significant predictor of the lead concentration ratio is the dust particle size class. The standard deviation of one concentration measurement is 15%. The sampler lead concentration ratio estimates are presented in Section 6.3.2.

8.2.4 Statistical Analysis of Gravimetric and Lead Analysis Data for Vacuum Cleaners

For the vacuum cleaner tests, the procedure of vacuuming the substrate for 40 seconds and measuring the associated weight change in the vacuum cleaner bag was repeated seven times. Dust was deposited onto the substrate before the second, third, and fourth vacuumings. After the seventh vacuuming, dust was shaken from the vacuum cleaner bag and analyzed for lead. These measurements were used to calculate the dust recovery, lead recovery, and ratio of the lead concentration in the dust collected by the vacuum cleaner to the lead concentration in the dust deposited on the substrate.

Gravimetric Data

Statistical analysis of the dust recovery (gravimetric) data for vacuum cleaners requires a definition of dust recovery and how to correct for accumulated dust from previous tests (carryover) and for carpet or upholstery fibers picked up in each test.

The vacuum cleaner tests used the following steps, also described in Section 4:

(1) Vacuum the substrate for 40 seconds and measure the combined weight of fibers and dust collected (vacuuming number 1).

(2) Deposit a measured amount of dust.

(3) Vacuum for 40 seconds and measure the combined weight of fibers and dust collected (vacuuming number 2).

(4) Repeat steps (2) and (3) two more times (vacuuming number 3 and 4).

(5) Vacuum for 40 seconds and measure the combined weight of fibers and dust collected (vacuuming number 5).

(6) Repeat step (5) two more times (vacuuming number 6 and 7).

(7) Shake dust from the vacuum cleaner bag into a container for lead measurement.

(8) Weigh the dust removed from the vacuum cleaner bag.

(9) Determine the lead content in the dust removed from the vacuum cleaner bag.

The analysis in Section 8.2.5, on the quantity of dust collected versus vacuuming effort, suggests that the weight of dust collected in the first vacuuming, before any dust is deposited, may not be a good estimate of the fibers and dust carryover affecting the subsequent vacuuming. The weight of dust collected on the last few vacuumings is often less than that collected on the first vacuuming. Assuming that (1) most of the dust deposited is collected in the second through sixth vacuumings, (2) the dust collected on the seventh vacuuming represents fibers and carryover, and (3) the same amount of dust from fibers and carryover affects vacuumings two through six, the following definition of dust recovery is used for the statistical analysis:

$$\text{Dust recovery} = \frac{(\text{weight2} + \text{weight3} + \text{weight4} + \text{weight5} + \text{weight6} - 5 \times \text{weight7})}{(\text{deposit1} + \text{deposit2} + \text{deposit3})}$$

where: weightN = the change in weight of the vacuum bag in the Nth vacuuming, and depositN = the weight of dust deposited in the Nth deposit.

The statistically significant terms in the final model are the substrate ($p < 0.0001$) and the vacuum cleaner ($p < 0.0001$). Based on an analysis of the residuals, the measurement variance decreased as the predicted dust recovery increased (with minimum variance for dust recoveries close to 100%). The statistical conclusions are unchanged and the estimates are similar when no regression weights are used. The results of the model are presented in Section 6.4.1. There was no evidence of significant serial correlation.

The pooled standard deviation of one dust recovery measurement was 9.2%, much better than required to meet the data quality objectives for the individual measurements and the averages for vacuum cleaner recovery. The half-width of the confidence intervals for dust recovery on combinations of substrate and vacuum cleaner (based on

a model with this interaction tern included) ranges from 4% to 18%, compared to the data quality objective of 15%. Overall, the dust recovery measurements for the vacuum cleaner tests achieved or nearly achieved the associated data quality objectives.

To determine the effect of alternate definitions of dust recovery, the final model for dust recovery (as defined above) was also fit using the following two alternate definitions for dust recovery:

$$HDR = \frac{(weight1+weight2+weight3+weight4+weight5+weight6+weight7-7 \times Fibers)}{(deposit1 + deposit2 + deposit3)}$$

$$LDR = \frac{(weight2 - weight7)}{(deposit1)}$$

where Fibers = the estimated 40-second uptake of fibers based on the dust preconditioning data (see Appendix B).

HDR is the total weight of dust collected, after correcting for fibers, divided by the weight of dust deposited. This represents an upper estimate of dust recovery corresponding to extensive vacuuming, under the assumption that the dust in the carpet has reached an equilibrium such that, on average, the dust carryover from the previous test is the same as the dust carryover to the next test.

LDR is the recovery for the first deposit of dust, corrected (approximately) for both fibers and dust carryover. Since the recovery for the first deposit of dust is generally lower than for later deposits, possibly due to less carryover, this represents a lower estimate of dust recovery. It corresponds to recovery based on a minimal amount of vacuuming (40 seconds).

The average HDR and LDR estimates for substrates are shown in Figure 6-8. The conclusions about which factors are significant predictors of vacuum cleaner dust recovery are similar when modeling the dust recovery, HDR, or LDR except that differences among vacuum cleaner are not statistically significant when modeling the HDR.

Lead Data

The lead recovery is the quantity of lead collected in the vacuum cleaner bag as a percentage of the lead deposited on the substrate. Because lead analysis of the entire vacuum cleaner bag and dust contained in it would be very difficult and would require a correction for lead in the bag itself (making the measurement imprecise), only that portion of the dust which was removed from the bag was analyzed. Assuming that the dust removed from the bag is representative of the dust in the bag, the dust recovery can be calculated as:

$$\text{Lead recovery} = \frac{\text{weight of dust collected} * \text{lead concentration in dust removed from the bag}}{\text{weight of dust deposited} * \text{dust lead concentration}}$$

The experimental procedures, with only one lead analysis per test, did not provide information to correct for possible lead carryover from test to test. Therefore, statistical analysis was used to identify possible lead carryover and, if necessary, to correct the estimates for carryover.

The values shown in the following table were removed as outliers and were very different than comparable measurements (ESR > 9.0 for both measurements). These outliers affect only the lead recovery and concentration ratio analyses. One possible explanation for the outliers, which cannot be checked, is that the lab technicians chose the wrong dust bag by mistake (either using dust from older homes rather than newer homes or using dust of a different size). MRI has checked these values and finds no known explanation for the unusual results.

Test number	Vacuum cleaner	Substrate	Nominal lead concentration	Dust particle size	Team	Concentration ratio	Lead recovery
1027(1-12)	C	Linoleum	Low	106-150	1	9.8	9.4
1079(1-25)	B	Wood	Low	212-250	1	5.1	4.8

As discussed below, the identification of the final model and the factors which affect vacuum cleaner lead recovery depend on which other factors are in the model. The only significant factor in the final model for vacuum cleaner lead recovery was the choice of vacuum cleaner ($p = 0.043$). Differences in measurement variance among tests with dust from older and newer homes were just statistically significant at the 0.05 level ($p = 0.04$). However, the identification of which factors affect the measurement variance depends on the model fit to the lead recovery data. Because the statistical results were insensitive to the use of weights in the model, and the variance differences were only marginally significant, no weights were used in the final model.

The average lead recovery across all tests was 103%, greater than the theoretical maximum of 100%. The difference between the average of 103% and the theoretical maximum is not statistically significant, so the difference may be due to random uncontrolled factors. However, given that the dust recovery averages 85% and thus not all of the dust is collected, it is reasonable to assume that not all of the lead is collected and that the true recovery is less than 100%. If this is true, the difference between the estimated average recovery of 103% and the true vacuum cleaner lead recovery may be due to factors other than chance.

Several possible explanations have been put forth to explain the high lead recovery, including lead carryover between tests, higher vacuum cleaner recovery of leaded dust than non-leaded dust, lead release from substrate samples (particularly carpets), and differential recovery of leaded and non-leaded dust from the vacuum cleaner bags. Of

these explanations, the differential recovery of leaded and non-leaded dust from the vacuum cleaner bags provides the most likely explanation. On average, only 26% of the dust in the vacuum cleaner bags was removed for lead analysis, leaving much of the dust in the bags. Leaded particles may be more easily shaken from the bag.

Regression was used to test if lead carry-over, or differential removal of dust from the vacuum cleaner bags, might explain the high lead recoveries. The weight of dust removed from the bag as a percentage of weight of dust collected by the bag, called the dust removal, was added to the model to determine if dust removal was related to lead recovery. Terms were also added to assess serial correlation related to successive tests within substrates, and to successive tests using the same vacuum cleaner, and to assess trends over time.

None of these terms were statistically significant. However, a separate analysis of the dust removal data showed that the dust removal depended on the dust particle size. This finding may also be relevant to the lead recovery since the relationships between dust particle size and dust lead concentration were different between dust from newer homes and from older homes (see Section 6.2). It was therefore decided to add a term for interaction between the nominal lead concentration (dust from older or newer homes) and dust removal. This interaction term was highly significant ($p=0.0021$). In addition, an interaction term between substrate and vacuum cleaner was also significant ($p = 0.0228$). The relationship between dust recovery and the vacuum cleaner and substrate tested is shown in Figure 6-12. The standard deviation of a single vacuum cleaner lead recovery measurement is 27%. The vacuum cleaner lead recovery estimates are discussed in Section 6.4.2.

If the leaded dust tends to be shaken out of the vacuum cleaner bag easier than the non-leaded dust, then the initial dust shaken from the bag will have a higher lead concentration than the dust remaining in the bag. Additional efforts to remove dust from the bag may remove dust with a lower lead concentration than the dust initially removed. In this case, one would expect the lead concentration in the removed dust to decrease with increasing effort to remove the dust from the vacuum cleaner bag. If (1) the lead recovery based on the lead concentration in the initial dust removed from the bag was 103%, (2) the true lead recovery was 85%, and (3) the relationship between dust removal and lead recovery was linear such that the lead recovery was estimated to be 85% when the dust removal was 100%, then the expected slope relating the lead recovery to dust recovery would be -0.18 (i.e., (103-85)/100).

By this simple argument, the expected parameter estimate for the dust removal would be negative and roughly -0.18. While other more complex models might suggest other values, this value provides a guide to evaluate the regression results.

For dust from newer homes with low dust lead concentration, the slope parameter is -1.14. This is in the expected direction and somewhat larger in magnitude than expected, although its confidence interval is large, from -0.21 to -2.07. For dust from older homes with high dust lead concentration, the slope parameter is 0.77. This is not

in the expected direction, but its confidence interval is also large, from -0.06 to 1.60. These parameters are difficult to interpret because of the large differences between the parameters for dust from older and newer homes and the large magnitude of the estimated slopes.

A model for the dust removal indicates that many factors affect it, including the following:

- Dust loading ($p < 0.0001$) - - more dust, as a percentage of the dust in the bag, was removed for tests with low dust loading than for tests with high dust loading. It was more difficult to get enough dust for lead analysis from the tests with low dust loading and, therefore, perhaps more effort was used.

- Nominal dust lead concentration ($p = 0.0039$) - - more dust was removed in tests using dust from older homes (high lead concentration) than newer homes. This result is consistent with the assumption that the leaded dust is easier to remove than the non-leaded dust.

- The combination of substrate and vacuum cleaner ($p = 0.0471$) - - this may in part reflect the varying difficulty in removing dust from the differently constructed and shaped vacuum cleaner bags.

- Dust particle size class ($p < 0.0001$) - - the dust removal efficiency increased as the dust particle size increased.

- The combination of dust loading on the substrate and dust particle size class ($p = 0.0001$) - - the pattern of dust removal from the vacuum cleaner bag as a function of dust loading and dust particle size is difficult to interpret. For each dust particle size class, high dust removal for tests with high dust loading is associated with low dust removal for tests with low dust loading. Similarly, low dust removal for tests with high dust loading is associated with high dust removal for tests with low dust loading .

- Operator ($p = 0.0034$) - - one vacuum cleaner operator removed, on average, 70% more dust from the bags than the other operator.

If the dust recovery depends on the dust removal and the dust removal depends on the factors above, then the observed dust recovery <u>may</u> appear to depend on the factors above through the dust removal. The regressions which include dust removal as an independent variable provide a correction for differential dust removal. However, the results are difficult to interpret and do not explain the high lead recovery estimates, particularly for the dust with high lead concentration, which is of most concern.

On the average, 26% of the lead deposited on the substrate is removed from the vacuum cleaner bag.[14] The remaining 74% of the deposited lead is in (1) the vacuum cleaner bag, (2) the substrate, (3) other parts of the vacuum cleaner, or (4) other areas of the test room or expelled into the air. The estimates of lead recovery are uncertain due to uncertainty in the dust removal. At a minimum however, it is possible to say that average lead recovery is greater than 26%, based on the worst case assumption that all of the leaded dust is removed for lead analysis, leaving only non-leaded dust in the bag. Because of the difficulty in interpreting the coefficients in the model for vacuum cleaner lead recovery (which included the dust removal interaction with nominal lead concentration), tentative conclusions are as follows:

- Vacuum cleaner lead recovery may depend on the combination of vacuum cleaner and substrate tested.

- Measured vacuum cleaner recoveries average about 103%, but, the measurements are difficult to interpret because of the methods employed and conflicting statistical results.

Concentration Ratio

The concentration ratio is the ratio of the lead concentration in the dust removed from the vacuum cleaner bag to the lead concentration in the dust applied. Two outliers were removed for the analysis, the same two outliers removed from the lead recovery analysis. In the final model, there were no significant predictors of the lead concentration ratio. The mean and standard deviation of the concentration ratio measurements are 112% and 27%, respectively. The vacuum cleaner lead concentration ratio results are presented in Section 6.4.2.

8.2.5 Statistical Analysis of Vacuuming Effort Data

Data were obtained on the quantity of dust collected by the vacuum (i.e. the increase in weight of the vacuum cleaner bag) before depositing dust (vacuuming 1), after each of three dust deposits (vacuumings 2, 3, and 4), and in three subsequent vacuumings (vacuumings 5, 6, and 7). All vacuumings were for 40 seconds. This data can be used to determine whether the dust deposited on the substrate is collected in the first 40-second vacuuming or whether additional vacuumings are required to remove the dust.

For the statistical analysis, the dust recoveries for vacuumings 2, 3, and 4 were defined as the ratio of the weight of dust collected in the vacuum bag to the weight of dust deposited just prior to the vacuuming. If there is no dust carryover, the average dust

[14]The average of both (1) the amount of dust removed from the bag for analysis as a percentage of the dust in the bag and (2) the amount of lead removed from the bag as a percentage of the amount of lead deposited on the substrate (after removing two outliers) are the same value, 26%, when rounded to two significant figures.

recovery for the three deposits are the same as the overall dust recovery. The weights of all dust deposits with the same nominal dust loading are quite similar.

For the statistical analysis, the dust recoveries for vacuumings 1, 5, 6, and 7 were defined as the ratio of the weight of dust collected in the vacuum bag to the average weight of dust deposited in the three deposits. By scaling the weight increases by the average dust deposit, the weight of dust collected on vacuumings 1, 5, 6, and 7 are put onto the same scale as the dust recovery for vacuumings 2, 3, and 4. Not counting the effect of fibers, the sum of the dust recovery, as defined here, over all vacuumings divided by weight of dust deposited in the three deposits, estimates the overall dust recovery.

The statistical analysis was used to describe the pattern of dust recovery versus vacuuming effort for each substrate only after correcting for factors which affect the dust recovery. The full analysis of dust recovery is presented in Section 8.2.4. Because the descriptive nature of the analysis, the model ignored nested effects for the multiple measurements within a test and possible serial correlation of measurements within a test.

Because the measurement variance appeared to vary among observations and to affect the selection of the model, preliminary regression weights were used to identify a preliminary model from which the final regression weights were determined, using the following steps:

(1) Remove apparent outliers and get a preliminary fit to the data.

(2) Analyze the residuals to determine preliminary regression weights.

(3) Model the data using a weighted analysis to identify a preliminary final model.

(4) Determine the final regression weights.

(5) Based on the final regression weights, formally identify and remove outliers and fit the final model. One term was removed from the preliminary final model to obtain the final model.

The model for the final regression weights predicts the measurement standard deviation as a function of dust loading (dust recovery is more variable based on smaller dust loadings), nominal lead concentration, dust particle size class, substrate (measurements on carpet are more variable than on other substrates), and the number of the vacuuming within the test (vacuumings 2, 3, and 4, with higher recoveries, have more variable measurements).

Four observations were identified as outliers and were removed from the analysis. The test number and vacuuming number of the outliers are: vacuuming 1 of test 2033 on

linoleum, vacuuming 1 of test 2020 on wood, vacuuming 7 of test 1013 on carpet, and vacuuming 1 of test 2006 on carpet. All of these outliers were more than five standard deviations from their estimated mean. The weighted residuals were used to identify outliers in the final model. Inclusion or exclusion of the outliers made very little difference in the estimates.

The final model for dust recovery versus vacuuming effort had terms for interactions between the vacuuming number and both dust loading and substrate, the interaction between vacuum cleaner and substrate, and a term for dust particle size class. The interaction between substrate and vacuuming number accounted for most of the prediction sum of squares. The predicted least square means for the substrate and vacuuming number interaction are shown in Figure 6-13 The implications of these results for the vacuuming effort are discussed in Section 6.4.2.

The amount of material (dust and fibers) collected in the last three vacuumings is often less than that collected in the first vacuuming before any dust is deposited. Thus, the weight of material collected in the first vacuuming appears to provide a poor estimate of the effect of fibers and dust on subsequent vacuumings. Because of this, it was decided to use the weight of dust collected in the last vacuuming to correct for fibers and dust carryover in the analysis of dust recovery, as discussed in Section 8.2.4.

8.2.6 Statistical Analysis of Sampling and Measurement Precision

Lead Measurement Precision

The measurement error (or variation) is the difference between the observed measurement and the true value being measured. It can be described mathematically as the sum of several independent sources of error, called components of variance. The variance of the measurement error is the sum of the variance of the components contributing to the error. The error components for measurements of lead are shown in Table 8-2.

Some of the samples were analyzed using the GFAA analysis and others using the ICP analysis. Because all GFAA samples were analyzed in the same batch, it is not possible to estimate the variance of the preparation batch and instrument batch components for the GFAA method. The results for the ICP analyses and the GFAA analyses are presented separately.

Variance Components for ICP Samples

Because all the samples from one preparation batch were generally analyzed in the same instrument batch, the measurement errors for the preparation and instrument batch components cannot be estimated independently. Similarly, sample variation within a preparation batch and within an instrument batch cannot be estimated independently. The samples sent for lead analysis can be divided into the different

types shown in Table 8-3. Although these samples can be used to estimate different components, estimates of individual components are difficult to determine and compare because different types of samples may have slightly different factors contributing to each component. Table 8-3 shows the components which can be estimated from measurements on different types of samples.

The analysis of variance components assumed that (1) the instrument batch and preparation batch components were confounded and could not be estimated separately and (2) the variance of the components depended on the concentration being measured but were similar for samples with the same lead concentration. The differences among batches are expected to affect all samples with similar lead concentration in a similar way, regardless of the sample type. This relationship is maintained in the estimates when all samples with similar concentration are analyzed together.

The model fit to the data had a term for sample type and a random effect term for the instrument batch. A separate analysis was performed for each group of samples with the similar lead concentration. In the analysis of the samples with zero lead concentration, one apparent outlier was removed from the interference check standards.

Table 8-2 Variance components for lead measurements

Variance component	Source
Test conditions	Variation in the lead recovery among replications of the test conditions
Sampling	Variation among the possible samples of dust, only one of which was collected for analysis.
Preparation batch	Variation in the procedures and reagents among sample preparation batches, only one of which was used to prepare the digestate for analysis.
Preparation	Within-preparation batch variation in the lead concentration in the digestate among the possible digestate beakers.
Instrument batch	Variation in the instrument condition and calibration among instrument batches.
Measurement	Variation in the measured lead concentration due to variation (assumed to be random) in the instrument's measurement process.

Table 8-3 ICP variance components which can be estimated from each type of sample

Sample type	Lead (µg/mL)	Components which can be measured	Comments
Instrument calibration blanks	0	[Instrument batch] [measurement]	Low-calibration standard
Interference check	0	[Instrument batch] [measurement]	Interference check standards with no lead
Method blank	0	[Instrument batch] [measurement]	Blank samples prepared for digestion
Field blank	0	[Instrument batch + preparation batch] [preparation + measurement + sample]	Blank prepared during the experiment and sent for analysis
Detection limit	.1	[Instrument batch] [measurement]	Standard with concentration near the detection limit
Interference check standards with lead	1	[Instrument batch] [measurement]	Interference check standards with lead
Spiked samples	4	[Instrument batch] [measurement]	Spiked samples with wipes excluded from the analysis
Continuing calibration verification	10	[Instrument batch] [measurement]	Mid-calibration standard
Independent calibration verification	10	[Instrument batch + measurement]	Independently prepared mid-calibration standard
High-calibration standard	20	[Instrument batch + measurement]	High-calibration standard
Standard reference material	Depends on dilution	[Instrument batch + preparation batch] [preparation + measurement + sample]	Variance is affected by interferences

The analysis output provided estimates of the average measurement for each batch and the variance of the measurements within a batch and the variance of the batch averages. The sum of the within batch and batch average variance components is the variance of one independent measurement associated with the laboratory analysis. For discussion and presentation, these variances are expressed as standard deviations (the square root of the variance) which have the same units as the measurements.

Figure 8-4 shows a plot of the standard deviation of the within batch measurement component, the instrument batch component, and the sum of these two variance components. The measurement component could not be estimated for the high calibration standards because there was only one such measurement per instrument batch.

Both the standard deviation of the within batch measurement component and the standard deviation of the batch component increase roughly linearly with the lead concentration in the sample. This linear relationship between standard deviation and concentration is typical for many laboratory concentration measurements and generally applies to all of the variance components. The within instrument batch variance is consistently less than the between batch component of variance. The variance for the spiked sample measurements is greater than predicted by the trend for the other samples. Only the spiked, method blank, and field blank samples passed through the preparation step. The method blank and field blank samples have zero lead, assuming no contamination. For these samples, the components associated with the preparation step would be small because the lead concentration was small. The method and field blank samples exhibited no greater variance than the calibration blank and interference check samples that also had no lead. On the other hand, the lead concentration in the spiked samples may have been affected by the preparation step. The increased variance for the spiked samples most likely represents the contribution of the preparation and preparation batch components.

A simple regression line was fit to predict the standard deviation of the combined between batch and measurement components. The prediction line is shown as a dotted line in Figure 8-4. The method spike samples were not used to fit the regression. However, the difference between the variance for the method spike samples and the predicted measurement error using the regression line was used to estimate the standard deviation of the error associated with the preparation step. This estimated coefficient of variation was 3.76%. The predicted standard deviation of a single independent measurement, represented by the regression line, was used to estimate the coefficient of variation of the lead measurements as a function of instrument response.

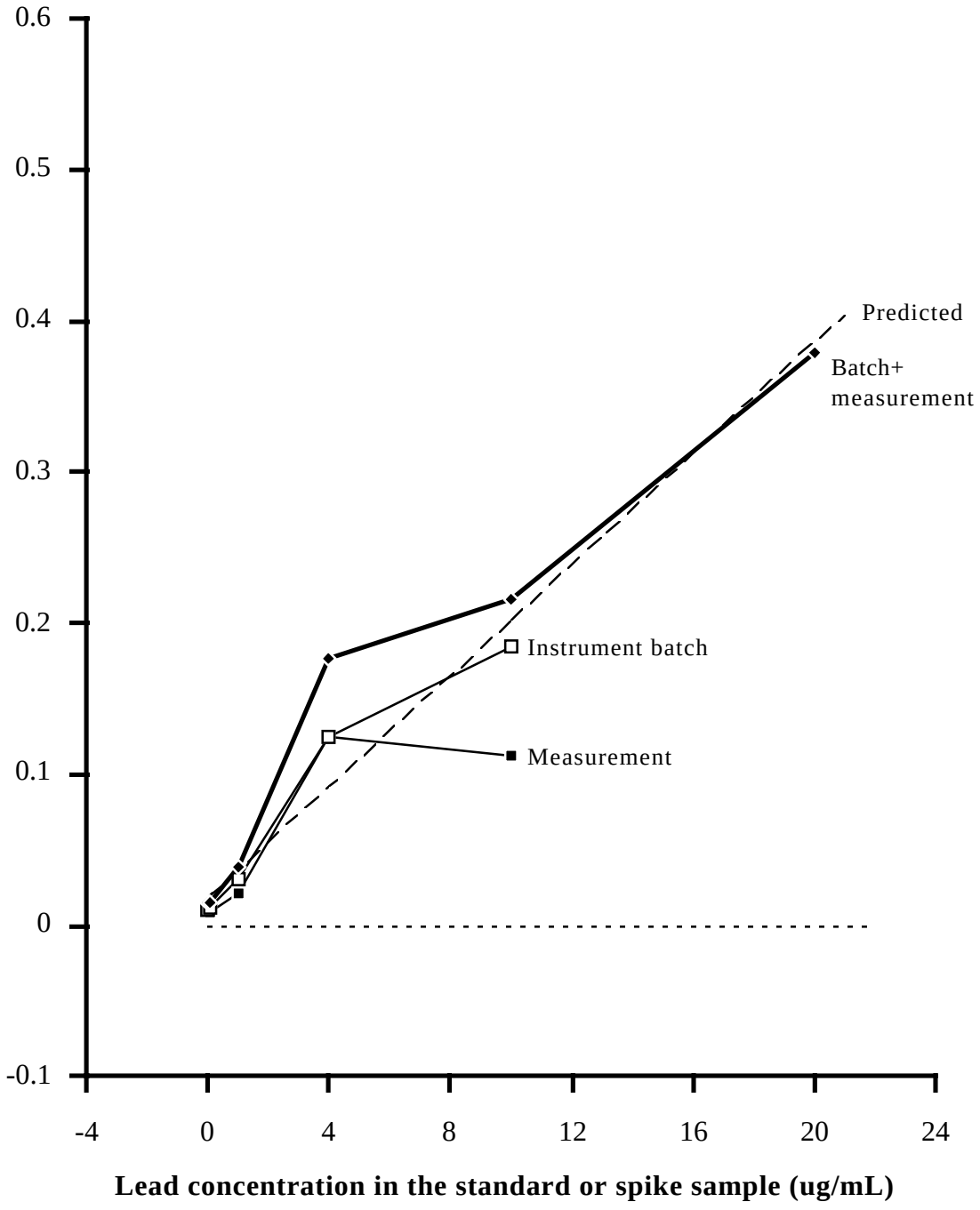


Figure 8-4 Standard deviation of the variance components as a function of lead concentration in the instrument sample after any dilution

Figure 8-5 shows the predicted coefficient of variation associated with lead measurements as a function of the instrument response and a histogram of the observed instrument response for the dust samples in the study. For higher instrument responses, the coefficient of variation for lead measurement is about 2% and is roughly independent of the instrument response. For lower instrument responses, the coefficient of variation can be considerably greater than 2% and can approach 20% for samples with instrument response at 0.1 μg/ mL (the response below which GFAA analysis was used). Many of the samples had associated instrument responses below 1 μg/mL with corresponding coefficient of variations above 4%.

The measurement bias (average measured - known lead concentration) for each batch as a function of the known lead concentration is shown in Figure 8-6. For samples with higher instrument response, the bias associated with each instrument batch is roughly constant. For samples with lower instrument responses, the bias varies considerably among batches and for different instrument responses. The relatively high bias for larger instrument responses for instrument batch E12023B is reflected in the instrument drift shown in Figure 9-6. The differences among the batch averages are statistically significant ($p<.01$ for all but the high calibration standards).

Figure 8-6 suggests that, for most samples, the bias in the lead measurements is less than 10% compared to the calibration standards. For the analysis of lead recovery, a correction for the bias in the lead measurements may be possible by including a term for an interaction between instrument response and instrument batch. However, due to the relatively large expected magnitude of the sampling error, such a correction may not be useful.

Variance Components for GFAA Samples

The GFAA QC and calibration samples provide some information on the magnitude of the variance components for lead concentration based on the GFAA method. Since all GFAA samples were analyzed in the same batch, only the within batch variance can be estimated. As with the ICP measurements, the measurement variance appears to increase with instrument response (after removing one outlier from the calibration blanks). The coefficient of variation of the continuing calibration standards is 2.2%, suggesting that the measurement variation for the GFAA methods, as measured by the coefficient of variation, is similar to that for the ICP method.

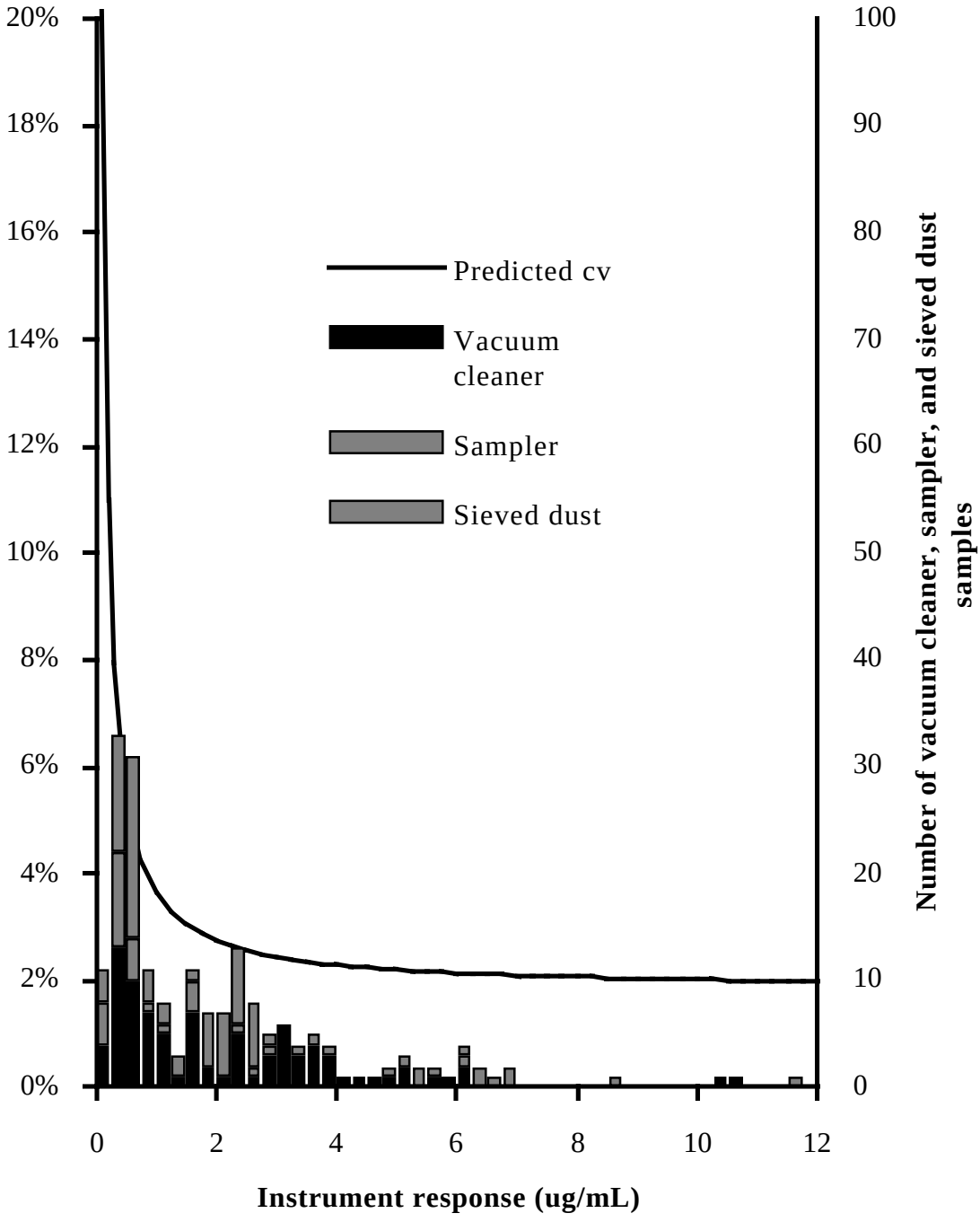


Figure 8-5 Predicted coefficient of variation (cv) associated with lead measurement as a function of the instrument response and histogram of the observed instrument response for the dust samples in the study

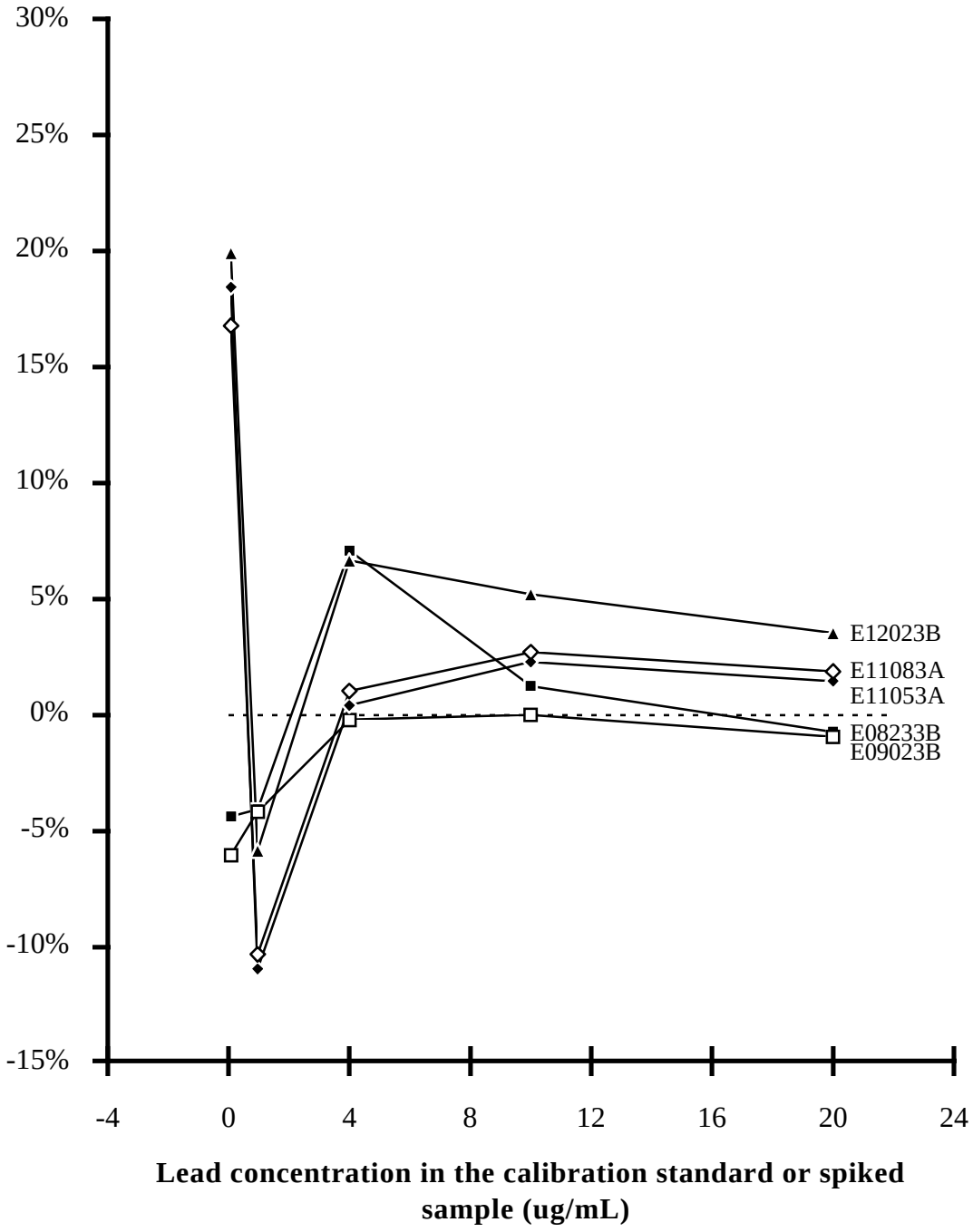


Figure 8-6 Measurement bias for each instrument batch as a function of the known lead concentration

Variance Component Associated with Dust Collection and Sampling

The coefficient of variation of one lead recovery measurement on a dust sample can be estimated from the measurements on standard reference materials and on sieved dust. The coefficients of variation of measurements on sieved dust are discussed in Section 8.2.2 and range from about 5% to 20%, except on dust in the largest dust size class. The coefficients of variation of measurements on the standard reference materials are discussed below.

Due to the small number of standard reference material samples, separate estimates for the variance components were not calculated. The coefficient of variation of the recoveries provides a measure of the combined effect of the variance components. For the samples analyzed using ICP, for SRM 1646 (with the lower lead concentration and particular problems with interferences), the coefficient of variation of the recoveries is 10.5%. For SRM 2704, the coefficient of variation is 8.6%.

For the purpose of estimating the coefficient of variation associated with the dust sampling component, the following assumptions are used: (1) the coefficient of variation of lead measurement is 3% (see Figure 8-5), (2) the coefficient of variation due to batch differences is 3.8%, and (3) the coefficient of variation of a lead measurement in a sample of dust is 11% (compared to estimates of 8.6%, 10.5%, and 5% to 20%). Using these assumptions, the coefficient of variation of the sampling component is:

$$\sqrt{.11^2 - 0.03^2 - .038^2} = .099 = 9.9\%$$

Thus, most of the variation in the lead measurement on a sample of dust is associated with the sampling of the dust.

Variance Component Associated with Test Conditions

The coefficient of variation of lead recovery measurements between tests conducted under the same conditions can be estimated from the error variance from the statistical models for lead recovery. The pooled standard deviation of the sampler lead recovery measurements is 17%. The average lead recovery for the BRM, CAPS cyclone, and wipe samplers is 69%, giving a coefficient of variation of 25%. For the vacuum cleaner lead recovery estimates, the coefficient of variation of the lead recovery measurements was about 26% (standard deviation of 27% divided by a mean of 103%). Because this is much greater than the roughly 9.9% associated with the dust sampling, most of the variation in the measurements is due to differences between tests.

9 QUALITY ASSURANCE

An independent evaluation of the sample collection and analysis activities on this work assignment was performed by the MRI Quality Assurance Officer (QAO) for the program. The evaluation included a system audit, performance audit, data audit, and data assessment. An explanation of each type of audit or review is given below, along with a discussion of the audit results. Also, Westat audited the data entry and statistical analysis procedures, as discussed in this section.

9.1 System Audit

The system audit performed by MRI for this work assignment was a qualitative examination of the vacuuming and analytical systems. Since the activities were significantly different for each system, a separate inspection was performed on each system. The results of the system audits are given below.

9.1.1 Vacuuming Task

A system audit on the vacuuming task was conducted on August 4, 1993. The areas inspected during this audit were the facility, equipment, and documentation. The facility was found to be adequate for the task. The equipment necessary for the activities was either in the facility or on order. No systematic problems were observed with the facility or the equipment.

Vacuum and wipe protocols were followed as per the QAPjP and no discrepancies or problems were found. Forms and laboratory notebooks were used for the documentation of work on this work assignment.

9.1.2 Analytical Task

The system audit of the analytical task was conducted on August 13, 1993. The areas inspected during this audit were personnel qualifications, sample control, sample preparation techniques (on samples similar to those being analyzed for this work assignment), and Standard Operating Procedures. No systematic problems were observed during this audit.

9.2 Performance Audits

For the analytical activities, two Performance Evaluation Samples (PESs) were prepared for each analytical preparation batch. The PESs were prepared by the project sample custodian using National Institute of Standards and Technology (NIST) Standard Reference Material (SRM). The two SRMs used for the dust PES material were

Estuarine Sediment (SRM 1646) with a lead level of 28.2 µg/g and Buffalo River Sediment (SRM 2704) with a lead level of 161 µg/g.

9.2.1 Performance Evaluation Sample Results

The individual results for the PESs used in the sample batches associated with this work assignment are given in Table 9-1. As noted in the table, the recovery of the PES did not meet the original DQOs for SRM 1646 in sample preparation batch No. 502. That is the recovery was below the lower control limit of 75%. This situation was investigated before proceeding with the analysis of the remaining sample batches.

The standard reference materials, NIST SRM 1646 and 2704, have been analyzed by ICP as blind PESs on several program tasks, and the recovery results have been control charted since late June 1991. A two year history of SRM 1646 recovery results is shown in Figure 9-1 (ICP sequence Nos. 1 through 62, covering the period from June 27, 1991, to September 8, 1993). In this figure, the results pertaining to the current work assignment are shown as full bullets and all other results are shown as hollow bullets. Figure 9-1 includes the results from two batches analyzed after batch No. 502 which do not pertain to this work assignment. Each data point represents a single recovery result.

Figure 9-1 shows an obvious change in the recovery pattern of SRM 1646 following ICP sequence No. 45. Prior to that date (August 6, 1992), difficulties were encountered in obtaining acceptable recoveries for SRM 1646. This material has a low lead concentration (28.2 µg/g) combined with high levels of other metals such as iron (iron:lead ratio exceeds 1,000:1), which causes interferences and necessitates further dilution of the samples. To correct for non-lead interferences, the analyst would perform serial dilutions of the digests. This in turn would result in lead levels for the blind SRM 1646 that were either below or within a few multiples of the instrumental detection limit, thus producing variable and sporadically poor recoveries.

Starting with ICP sequence No. 46 (May 3, 1993), action was taken to correct for non-lead interferences. This was achieved by (1) establishing a consistent serial dilution pattern of samples for both high levels of lead and high levels of spectral interferences and (2) by raising the interference check standard from 200 to 250 µg/mL. This resulted in more consistent but lower recoveries for lead in SRM 1646 PESs, as reflected in Figure 9-2. This figure shows recovery results for ICP sequence Nos. 46 through 108, covering the period May 3, 1993, through January 28, 1994.

Table 9-1 Percent recoveries of blind performance evaluation samples

ICP Sequence No.	Preparation Batch No.	SRM 1646[1]			SRM 2704[2]		
		Concentration (μg/g)		Recovery (%)	Concentration		Recovery (%)
		Certified	Found		Certified	Found	
56	501	28.2	22.07	78.28	161	152.7	94.87
60	502	28.2	18.94	67.15[a]	161	140.5	87.27
85	503	28.2	20.12	71.36	161	148.1	91.96
86	504	28.2	23.30	82.63	161	150.1	93.25
87	505	28.2	24.10	85.46	161	152.0	94.39
95	506	28.2	23.62	83.77	161	153.4	95.26
96	507	28.2	22.07	78.27	161	147.6	91.65
NA[3]	508	28.2	21.09	74.78	161	152.8	94.91

1 SRM 1646 accuracy DQOs for batch Nos. 501 and 502: target value is 100%±20% (warning limits) and ±25% (control limits)

2 SRM 2704 accuracy DQOs for all batches: target value is 100% ±20 % (warning limits) and ±25% (control limits)

3 Preparation batch No. 508 was analyzed using GFAA spectroscopy instead of ICP

a % recovery does not meet DQO of 75%

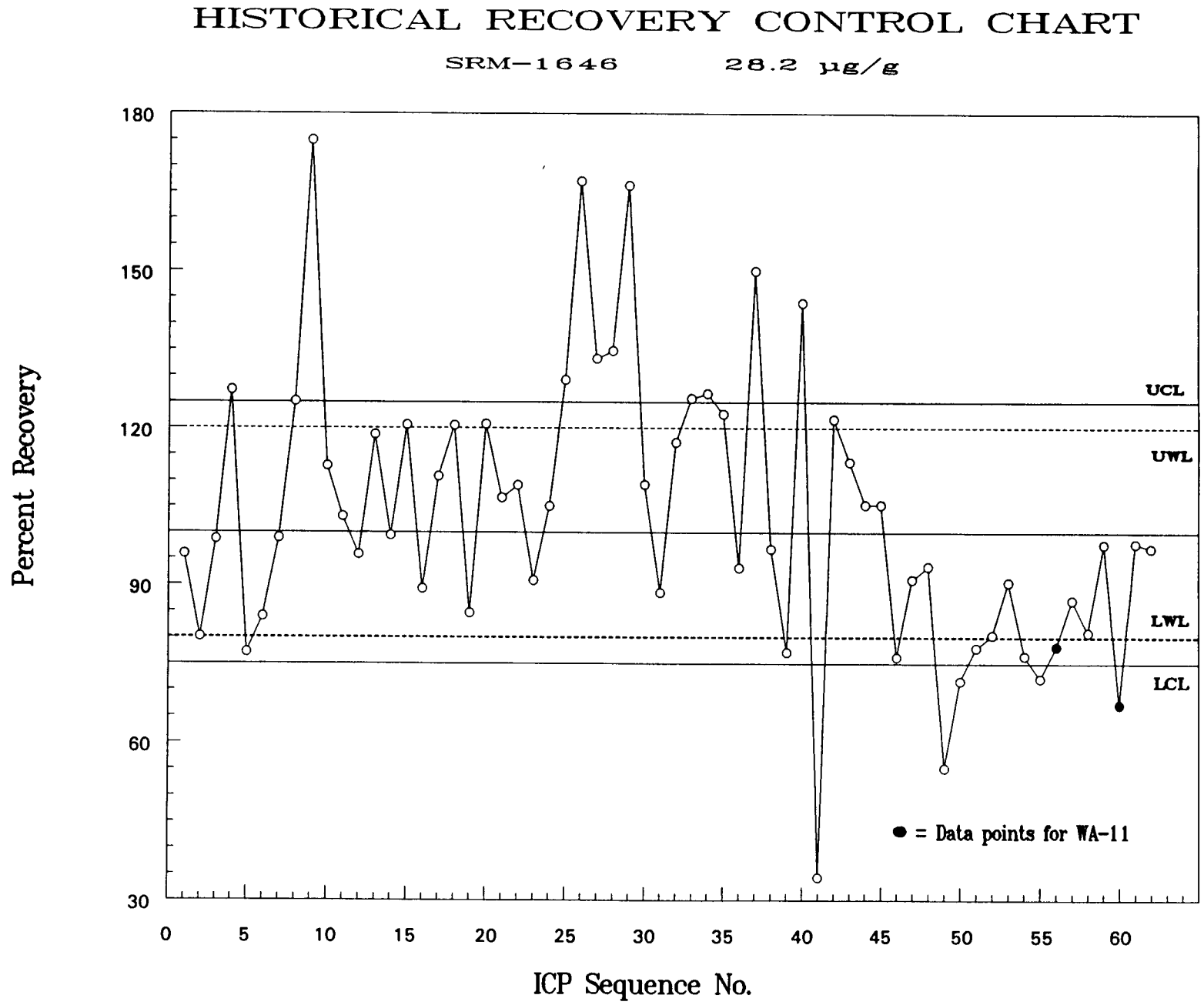


Figure 9-1 Historical X-bar (mean) QC chart for SRM 1646 recovery.

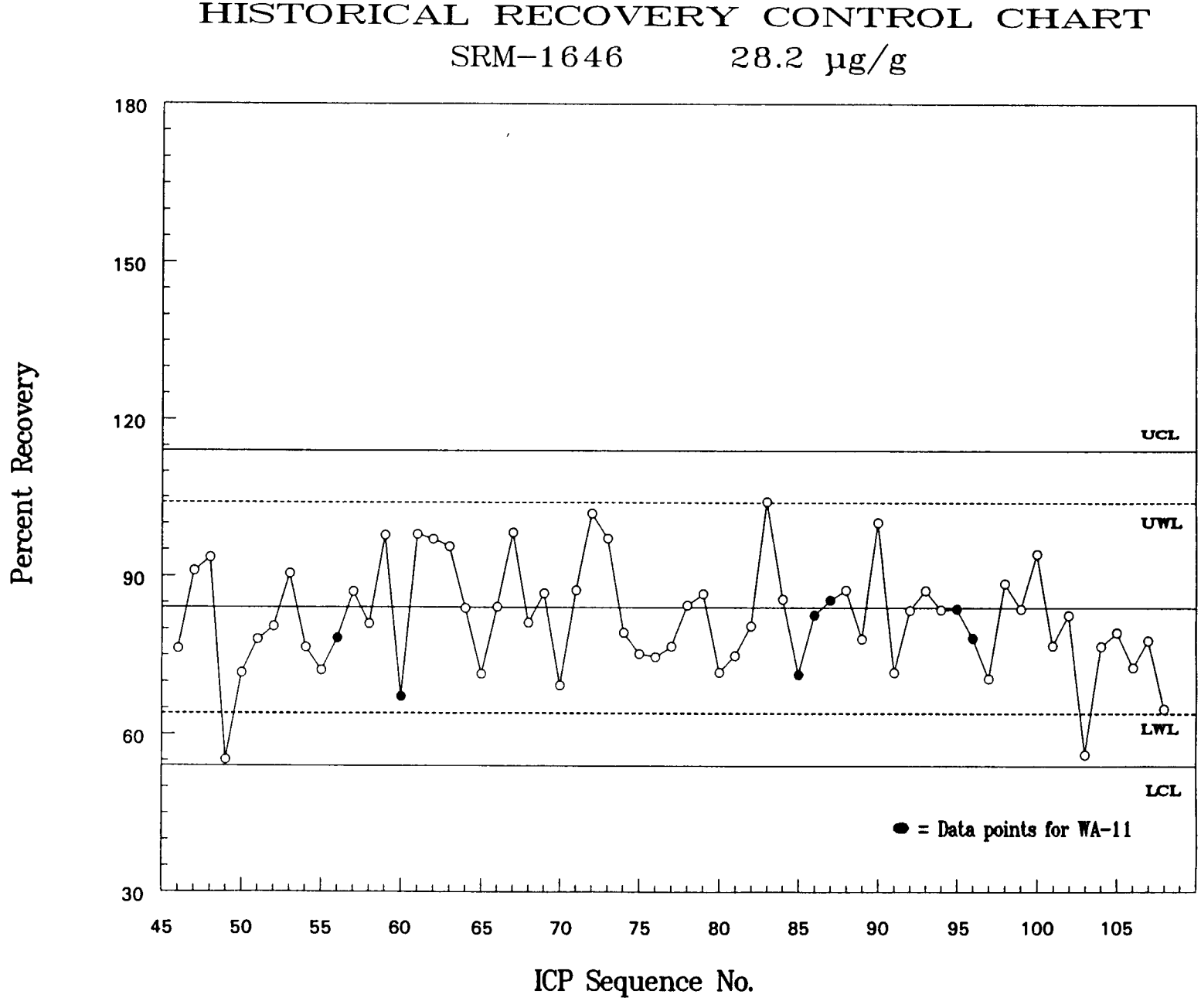


Figure 9-2 X-Bar (mean) QC chart for SRM 1646 recovery showing revised control and warning limits.

In the investigation of the low recovery for SRM 1646 in batch 502 (67.15%), it was recognized that this change toward consistent, but lower, recoveries was obtained after ICP sequence No. 46. It also was recognized that the original control limits of 100%±25%, which were arbitrarily selected, needed to be statistically determined. Therefore, revised control limits were statistically determined using the 16 results available at the time (beginning with ICP sequence No. 46 through ICP sequence No. 62) as given in Table 9-2. The mean value for these data was a recovery of 84% with a standard deviation of 10. Based on this information, the warning limits and control limits were statistically specified as:

Control limits = Mean ± 3 standard deviations = 84 ± 30%
Warning limits = Mean ± 1.96 standard deviations = 84 ± 20%

These statistically-based control limits were approved for this task and a QAPjP amendment record was prepared, dated October 29, 1993. After receiving approval, work resumed on the analysis of subsequent sample batches, and the results were all within the revised control limits. Moreover, these results, along with results for SRM 1646 on other sample batches not associated with this work assignment and included in Figure 9-2, support the validity of the revised control limits and their use for the intended purpose of identifying problems in sample analysis.

Based on the information discussed above and shown in Figure 9-2, it is clear that the results for SRM 1646 on this work assignment were not a problem and were in fact "in control," including the result for batch No. 502.

The historical control chart for SRM 2704 recovery results is shown in Figure 9-3 for completeness. This chart covers the period from June 27, 1991, to January 28, 1994, and reflects the fact that all results are within the control limits. Since the blind performance samples consisted of both SRM 1646 and SRM 2704 and both SRMs were prepared and analyzed during the same period, the results obtained from SRM 2704 show an analytical system that is in control with no systematic errors. These results also show that the problems with SRM 1646 were in the nature of the SRM rather than in the analytical system.

9.3 Data Audit

The data audit is a qualitative and quantitative evaluation of the documentation and procedures associated with the measurements to verify that the resulting data are of known and acceptable quality.

For this work assignment, two types of data were submitted for audit. The first type was primarily weight data obtained during the dust application and vacuuming activities. The second type was analytical data used to evaluate the lead concentrations in the sieved dust as applied to substrates and the dust recovered from the vacuum cleaners and samplers.

Table 9-2 SRM 1646: percent recovery of 16 blind control samples

ICP Sequence No.[a]	Analysis Date	Preparation Batch No.	Recovery (%)
46	05/03/93	XDV	76.24
47	05/03/93	XDT	91.00
48	07/22/93	601	93.47
50	07/28/93	804	71.71
51	08/03/93	809	78.04
52	08/14/93	801	80.47
53	08/14/93	802	90.46
54	08/16/93	803	76.53
55	08/16/93	807	72.21
56	08/23/93	501[b]	78.28
57	08/28/93	814	87.02
58	08/28/93	821	80.94
59	09/01/93	817	97.71
60	09/02/93	502[b]	67.15
61	09/08/93	811	97.88
62	09/08/93	812	96.96
		Number of samples =	16
		Mean recovery =	84
		Standard deviation =	10
		Coefficient of variation (%) =	12

[a] ICP sequence No. 49 results were not available at the time corrective action was taken

[b] Batch associated with present work assignment

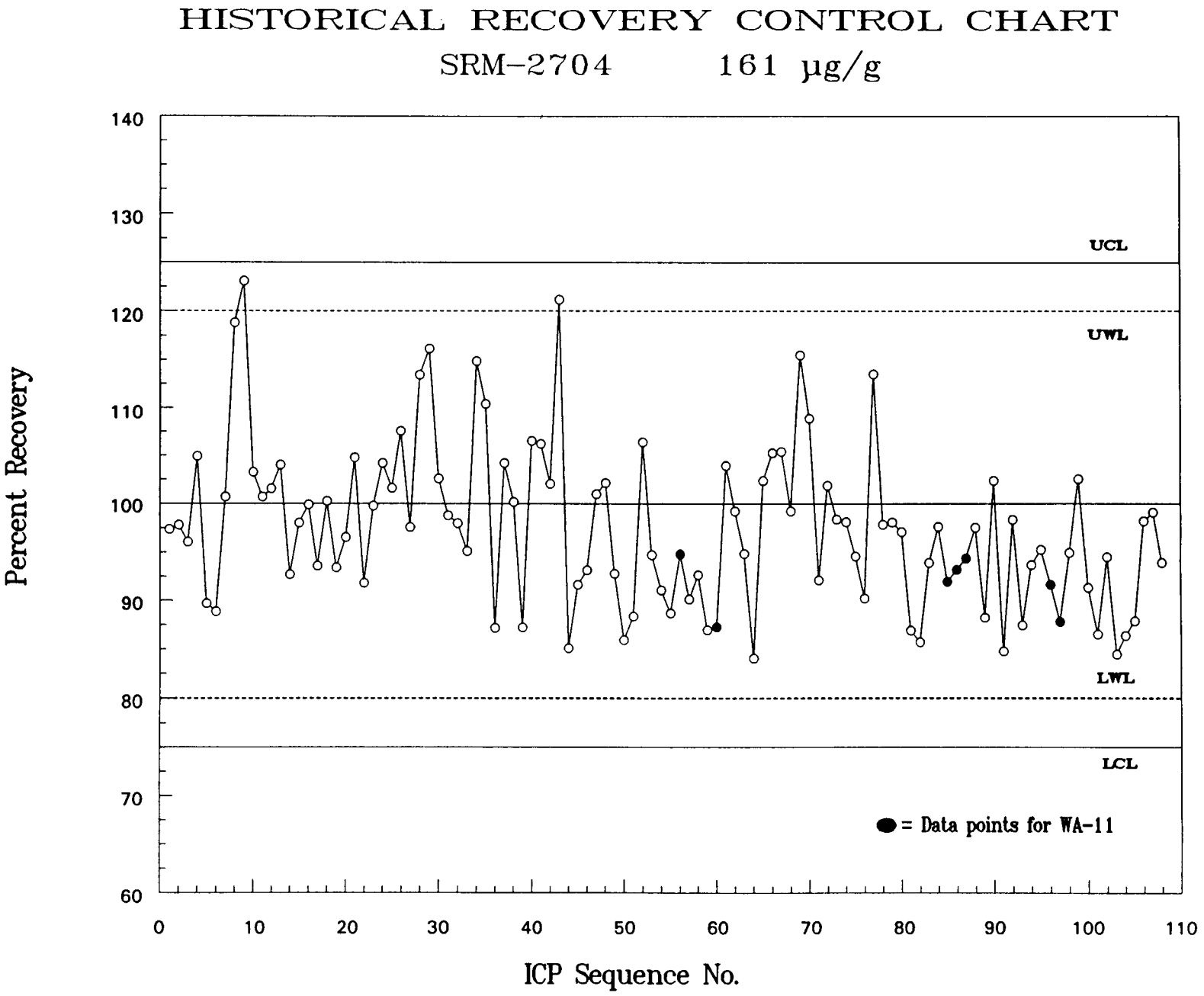


Figure 9-3 Historical X-bar (mean) QC chart for SRM 2704 recovery.

9.3.1 Vacuum Weight Data

Five data audits were conducted on dust weight data. These audits evaluated approximately 25% of the data collection and processing systems for the vacuum cleaner emission study, the carpet pre-conditioning study, and all the vacuum cleaner and sampler recovery data sets. The balances used for the weighing activities were serviced within the past year. Each balance was verified to be calibrated against weights traceable to NIST Standards and was operating properly. During each weighing session, check weights were used to verify that the response of the balance was accurate before the weighing of the samples (i.e., each day). No systematic errors were detected in the data audited, and any random errors found in the data were corrected prior to release of the data.

Of the 1,598 test weight results, a total of 595 (37.2% weights randomly selected within batches) were audited. Two random errors (one sample misidentification and on arithmetic error) were found and corrected. The estimated error rate, before correction, was 0.34% with lower and upper 95% confidence limits of 0.03% and 1.21%, respectively, based on a Poisson distribution. Adjusting for the two corrections made and the fact that one batch (360 test weights) was 100% checked and error-free, the average error rate for dust weight test results is estimated at 0.14% with a 95% confidence interval of 0% to 0.81%.

9.3.2 Analytical Data

The data audits were conducted on approximately 20% of the analytical data by personnel assigned to the QA Unit under the supervision of the QAO. The analytical data generated for this work assignment were audited to assure quality and reliability. The quality of the analytical data was evaluated using blind PESs prepared from NIST standard reference materials and internal quality control samples prepared by the analyst. The data obtained from these samples were evaluated against the DQOs and the measurement objectives for the analytical process as presented in the QAPjP and its appendices. Audits of the analytical data showed no systematic errors in the data measurement process. These data were found to be in compliance with the DQOs and measurement objectives, with the exception of the recovery (accuracy) data from three of the low-level, blind performance evaluation samples (NIST SRM 1646), as was discussed in Section 9.2 of this report.

Of the 222 analytical test results, 41 (18.5%) were randomly selected from within the sample batches and were audited. One (1) random error that involved a dilution factor calculation where the spreadsheet had been changed to accommodate a larger dilution volume was found and corrected. The estimated error rate, before correction, was 2.4% with lower and upper 95% confidence limits of 0.24% and 13.7%, respectively, based on a Poisson distribution. Adjusting for the one correction, the average error rate for the analytical test results is estimated at 2.0% with a 95% confidence interval of 0% to 13.2%.

9.4 Data Assessment

All analytical data were reviewed to verify that all study requirements were met. Various sets of data were compared to the DQOs stated in the QAPjP. Where necessary, corrective actions were taken and documented in work assignment records. The following subsections document quality control results pertaining to sample preparation, instrument calibration, and data processing and statistical analysis procedures.

9.4.1 Sample Preparation QC Data

Potential laboratory contamination was assessed by the use of digestion blanks. These blanks were included in each sample preparation batch at the ratio of one blank for every 20 samples, with a minimum of one per batch. The DQO for the measured value of a digestion blank was set at 10 times the instrumental detection limit. The digestion blank results for each batch are shown in Table 9-3.

For all but two preparation batches, the levels found in the method digestion blanks (last column of Table 9-3) were below their respective calculated sample detection limit. The levels in one blank of batch No. 505 and in the three blanks of batch No. 508 were above their respective calculated sample detection limit. However, all but one of these blank levels were below 10 times the calculated sample detection limit (i.e., the DQO). One blank level in batch 508 was above the DQO. A cassette from the lot of cassettes that were in the collection laboratory was used as a blank for batch 508. Although the levels of lead found were above the limit of detection, they were within the range of lead levels found in blank cassettes from previous studies.

To evaluate the accuracy and precision of the laboratory analytical procedures, replicate spike QC samples were included in each sample preparation batch at the ratio of two replicate spike samples for every 20 samples, with a minimum of two per batch. Percent recoveries were calculated for each spike sample. From these results, the range of duplicate percent recoveries was calculated as the difference between the highest and lowest recovery in each batch. All percent recoveries met the DQOs as stated in the QAPjP: lower and upper control limits of 75% and 125%, respectively. The ranges of replicate percent recoveries were all below the upper control limit of 20%. All recovery statistics are shown in Table 9-4 and in Figures 9-4 and 9-5, including the associated DQOs.

Table 9-3 Method digestion blank results

Analytical batch No.	Preparation batch No.	Sample type	Instrumental detection limit (µg/mL)	Digestion volume (mL)	Calculated sample detection limit (µg)[a]	Data quality objective[b] (µg)	Value found (µg)
E08233B	501	Bottle	0.0129	25	0.323	3.23	< 0.32
	501						< 0.32
E09023B	502	Bottle	0.0408	25	1.020	10.20	< 1.02
	502						< 1.02
E11053A	503	Bottle	0.0331	25	0.828	8.28	< 0.83
	503						< 0.83
E11083A	504	Bottle	0.0240	25	0.600	6.00	< 0.60
	504						< 0.60
	505	Bottle	0.0240	25	0.600	6.00	0.85
	505						< 0.60
E12023B	506	Bottle	0.0184	25	0.460	4.60	< 0.46
	506						< 0.46
	507	Wipe	0.0184	100	1.840	18.40	< 1.84
	507						< 1.84
V12073A	508	Cassette	0.4718 µg/L	0.025 L	0.0118	0.118	0.08
	508						0.07
	508						0.17

a Sample detection limit (µg) = instrument detection limit (µg/mL) x digestion volume (mL)

b DQO: Total µg found is to be less than 10 times the sample detection limit (µg)

Table 9-4 Method spike replicate results

Analytical batch No.	Preparation batch No.	Sample type	Method spike recovery (%)	Range[1] of replicate % recoveries
E08233B	501	Bottle	104.58	
			104.40	
			109.65	
			109.73	5.33
E09023B	502	Bottle	101.73	
			96.83	
			101.93	
			98.41	5.10
E11053A	503	Bottle	101.10	
			98.98	
			98.58	
			102.93	4.35
E11083A	504	Bottle	104.54	
			103.18	
			103.35	
			97.86	6.68
E11083A	505	Bottle	103.08	
			98.46	
			98.88	
			98.90	4.62
E12023B	506	Bottle	109.95	
			102.66	
			102.22	
			111.96	9.74
E12023B	507	Wipe	99.34	
			96.48	2.86
V12073A	508	Cassette	98.40	
			103.70	5.30

[1] Range of replicate % recoveries = highest - lowest % replicate recovery
DQOs: Upper warning limit = 15%; upper control limit = 20%

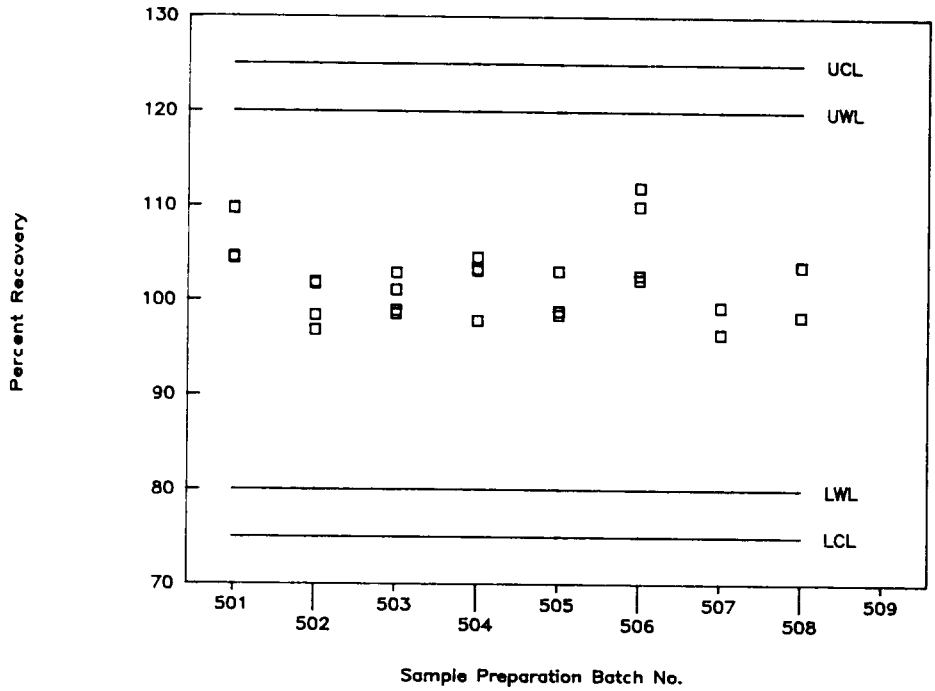


Figure 9-4 Method spike replicates: recovery (%)

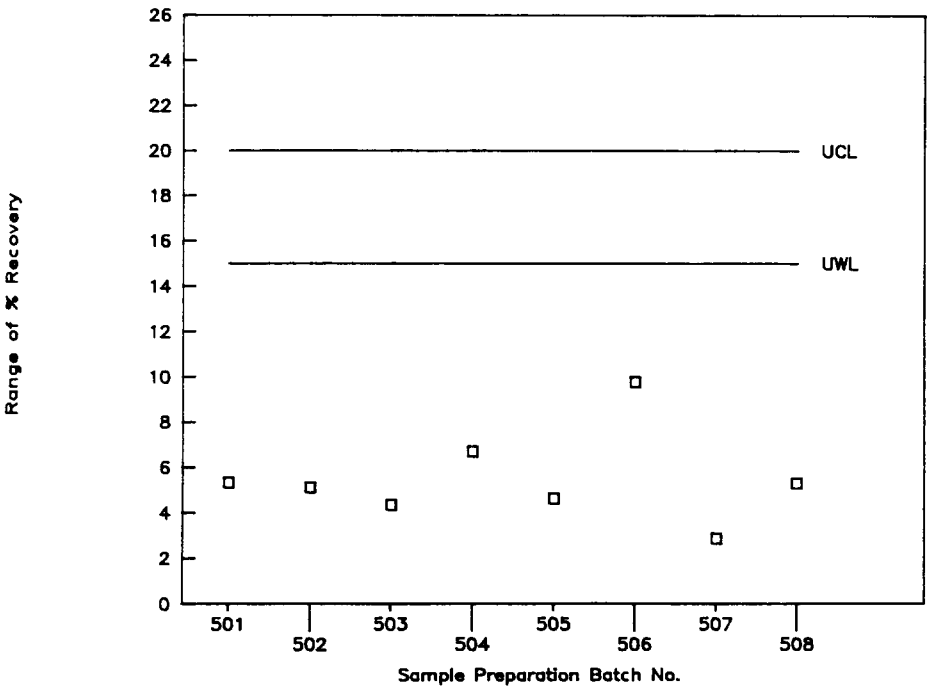


Figure 9-5 Method spike replicates: recovery range (%)

9.4.2 Instrumental Analysis QC Data

A series of instrumental QC samples were analyzed with each analytical batch to determine the performance of the instrumental measurements independently of sample preparation. The following summarizes the results from these QC samples.

Initial calibration blanks (ICBs) were analyzed using one per run at the beginning of each run. The ICBs and continuing calibration blanks (CCBs) were prepared by the analyst on the day of analysis, using the same acid matrix that was used for sample detection at the instrument. All measured values were below their respective instrumental detection limits.

CCBs were used to verify blank response and freedom from carry-over. These blanks were analyzed after each continuing calibration verification (CCV). The DQO for these blanks was identical to that for ICBs. Of the 65 CCB samples run, 60 had levels below their respective instrumental detection limits. One CCB sample in each of batch Nos. 501, 504, and 508, and two in batch No. 505, were above their respective instrumental detection limits. However, all measured CCB values were below 10 times the instrumental detection limit; therefore, all CCB values met the DQO.

Initial calibration verification samples (ICVs) were analyzed once per run following calibration. These samples were analyzed to verify proper instrumental calibration prior to the start of the analytical batch, and were from alternate stock standards than those used in the original calibration. All ICV sample values met the DQO of ±10% of the known value. The results are shown in Table 9-5.

CCV samples were analyzed using one sample during or after calibration, after each set of 10 samples, and at the end of the analytical run. These samples were analyzed to monitor instrumental drift, utilizing the original mid-point calibration standard. The measured values of these samples were all within ±10% of their respective initial values. The CCV sample results are summarized in Table 9-6 and plotted in Figure 9-6.

Table 9-5 Initial calibration verification sample (ICV) results

Analytical batch No.	Sample type	Concentration (μg/g)		Recovery[1](%)
		Known	Found	
E08233B	Bottle	10	10.123	101.2
E09023B	Bottle	10	10.042	100.4
E11053A	Bottle	10	10.062	100.6
E11083A	Bottle	10	10.193	101.9
E12023B	Bottle and wipe	10	10.277	102.8
V12073A	Cassette	20	20.040	100.2
[1] DQO: Found value to be within ±10% of known value				

Table 9-6 Continuous calibration verification (CCV) sample results

Analytical batch No.	Preparation batch No.	Known value (µg/mL)	Found value (µg/mL)	Recovery (%)	Instrument drift (%)[1]
E08233B	501	10	10.111	101.1	
		10	10.286	102.9	1.7
		10	10.127	101.3	0.2
		10	10.208	102.1	1.0
		10	10.260	102.6	1.5
E09023B	502	10	9.9916	99.9	
		10	10.130	101.3	1.4
		10	9.9681	99.7	-0.2
		10	10.057	100.6	0.7
		10	10.178	101.8	1.9
E11053A	503	10	10.173	101.7	
		10	10.307	103.0	1.3
		10	10.401	104.0	2.2
		10	10.317	103.2	1.4
		10	10.387	103.9	2.1
		10	10.417	104.2	2.4
E11083A	504,505	10	10.204	102.0	
		10	10.210	102.1	0.1
		10	10.214	102.1	0.1
		10	10.327	103.3	1.2
		10	10.318	103.2	1.1
		10	10.484	104.8	2.7
		10	10.486	104.9	2.8
		10	10.356	103.6	1.5
		10	10.440	104.4	2.3
		10	10.538	105.4	3.3
E12023B	506,507	10	10.545	105.5	
		10	10.486	104.9	-0.6
		10	10.511	105.1	-0.3
		10	10.631	106.3	0.8
		10	10.711	107.1	1.6
		10	10.827	108.3	2.7
		10	10.732	107.3	1.8
V12073A	508	20	20.080	100.4	
		20	19.230	96.2	-4.2
		20	18.780	93.9	-6.5
		20	19.210	96.1	-4.3
		20	19.380	96.9	-3.5
		20	19.070	95.4	-5.0
		20	18.760	93.8	-6.6
		20	19.540	97.7	-2.7

[1] DQO: Instrument drift to be within ±10%

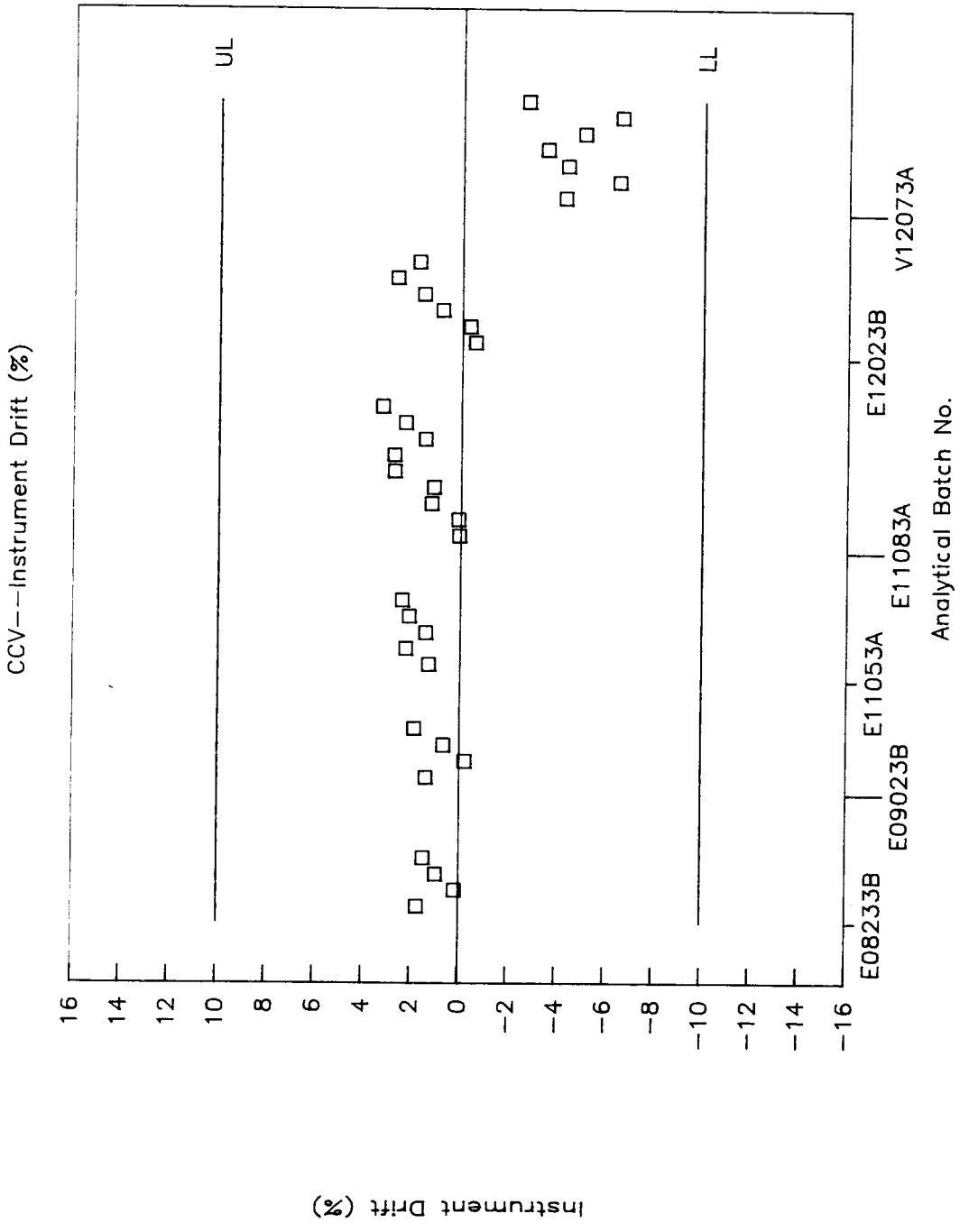


Figure 9-6 Continuous calibration verification sample (CCV) plots

9.4.3 Statistical Analysis QC Results

Quality control of the statistical analysis was achieved through two analyses of the data by the same analyst and peer review by another statistician. The data were initially analyzed to prepare preliminary results for EPA's review and to determine the most appropriate analytical procedures. After correcting a few minor errors in the data files (identified during the preliminary analysis and the final verification steps in the preparation of the data files), the analysis files were again prepared from the revised data files and the final analyses were performed. The programming for the final statistical analysis was independent of the programming used in the initial analysis. Statistical procedures used in the first analysis were carefully reviewed before being used in the second analysis. A Macintosh PC based statistical analysis program called JMP from the SAS Institute was used to analyze the data. The two analyses were separated by a period of about a month. Where applicable, the results from the different models were compared to identify features of the data which were not apparent from the primary analysis. In addition, both the statistical procedures used to analyze the data and the results from the statistical analyses were reviewed by a second statistician.

APPENDIX A: PILOT TESTS RESULTS FOR THE WIPE AND VACUUM STUDY

Pilot Tests for EPA's Wipe and Vacuum Study were conducted to test some of the procedures proposed for the full Wipe and Vacuum Study and to provide information for improving the design of the study. The objectives of the full Wipe and Vacuum Study are broad in scope: first evaluation of two kinds of dust collection methods (samplers and household vacuum cleaners) with multiple examples of each method; second estimation of lead recovery, dust recovery, and amount of dust expelled through the exhaust, with recovery assessments for multiple substrates, multiple amounts of dust, multiple particle size classes, and multiple dust lead concentrations. The results of the pilot tests were used to help select the solutions to the most important design problems encountered. This appendix describes the individual tests which together comprise the Wipe and Vacuum Pilot Study and the results of those tests.

A1.0 INTRODUCTION

A draft study design document for a full laboratory study was prepared by Westat, Inc. and reviewed by MRI and EPA for inclusion in the Quality Assurance Project Plan (QAPjP)[15] for the Wipe And Vacuum Study. During the development of the test design document, several uncertainties were identified regarding testing of vacuum cleaners. The first major uncertainty concerned the amount of dust that should be used on the substrates (e.g., carpet) for testing the dust and lead pickup efficiency of vacuum cleaners. Concerns about accuracy in determining dust removal efficiency raised questions about variability of weighing new bags used in vacuum cleaners (i.e., precision of tare weights). A related question concerned how much preconditioning of new carpets would be necessary so that the weight of carpet fibers picked up in the tests would be insignificant compared with weight of dust. A final question concerned whether new carpet should be used for each test (after preconditioning) or whether the same substrate could be used in several tests, without significant "carryover" from test to test.

In another area, a concern was the possibility that a significant portion of the dust used on the substrate might adhere to the brush and wand of the vacuum cleaner. If this were true, some dust would actually have been removed from the substrate but not included in the weight change of the bag.

Uncertainty about the amount of dust that should be used was also associated with determining lead removal efficiency. Lead in the dust could be determined either by digesting the entire vacuum bag or by removing dust from the bag for digestion and analysis. The amount of lead in the bag and captured dust would be affected by the lead content of the bag itself (blank level) if the amount of dust was small and could not

[15]Quality Assurance Project Plan for the Wipe and Vacuum Study. EPA Contract nos. 68-DO-0137 (Task 3-55) and 68-D3-0011 (Task 1-07). July 21, 1993.

be removed from the bag. Initial tests carried out on two blank bags indicated that, when including the bag in the lead analysis, the amount of dust used would likely have to be as large as 5 grams or more. It was therefore important to determine if a sufficient quantity of dust could be removed from vacuum cleaner bags.

The mechanics of carrying out the tests required a method of securing substrates in some suitable way for performing the vacuuming tests. A method described in ASTM F608-89 was a likely option, but the apparatus needed to be built and successfully used prior to the full laboratory testing.

Finally, there was uncertainty as to how dust emissions from the vacuum cleaners could be measured (i.e., dust that passes through the bag and is exhausted out of the vacuum cleaner). This uncertainty raised several questions about how dust could be fed evenly into the vacuum cleaners for such tests, and how the emissions could be sampled isokinetically for the emission measurements.

A1.1 Objectives

Having no information to answer the questions presented above, MRI, with the help of Westat, prepared a work plan for the pilot test[16]. The work plan was reviewed and approved by EPA, after which the pilot tests were performed by MRI. The tests were designed to determine dust quantities needed for the full study, to determine what preconditioning procedures were necessary, and to optimize the sampling protocols discussed in the QAPjP. The various tests were organized into the following five tasks:

Task 1	Determine the Stability of Tare Weights for New, Clean Vacuum Cleaner Bags
Task 2	Demonstrate a Method of Securing Carpet and Upholstery Substrates for Testing Vacuum Cleaners
Task 3	Determine if Preconditioning Procedures Would Allow Use of New Carpet in the Tests, and Determine if the Reuse of the Same Substrate for Each Series of Tests is Feasible
Task 4	Determine the Amount of Dust Needed for the Tests
Task 5	Develop and Demonstrate a Method for Measuring Exhaust Emissions from Vacuum cleaners

The detailed description of work performed in each of these tasks is provided in the study design presented in Section A2.

[16]Revised Work Plan for Pilot Tests. Wipe and Vacuum Study. EPA Contract No. 68-DO-0137. Work Assignment No. 55. MRI Project No. 9802-a(55). June 14, 1993

The following five sections of this report cover the study design and procedures (Section 2), the data collection (Section 3), the statistical data analysis (Section 4), and the discussion of the test results (Section 5).

A2.0 STUDY DESIGN AND PROCEDURES

The pilot tests were performed using four vacuum cleaners on two types of substrates, carpet and upholstery. The vacuum cleaners were: three canister types, subsequently denoted as A, B, and C and one upright, denoted as D. The following accessories were included with the purchased vacuum cleaners:

Vacuum Cleaner Code and Type	Vacuum Cleaner Accessories
Vacuum cleaner A (canister) without HEPA filter	Beater bar for use on rugs Upholstery attachment (including a brush) Hard surface attachment (including a brush)
Vacuum cleaner B (canister) without HEPA filter	Beater bar for use on rugs. (Power nozzle used on hard surfaces with beater bar stopped.) Upholstery attachment (with a brush)
Vacuum cleaner C (canister) with HEPA filter	Beater bar for use on rugs Upholstery attachment (no brush included) Hard surface attachment (including a brush)
Vacuum cleaner D (upright) without HEPA filter	Hose connection for upholstery attachment (including a brush) and hard surface attachment. (Insertion of hose stops beater bar and diverts suction to hose.)

The exhaust emission tests were conducted using each of the vacuum cleaners and dust which had passed through a 53 micron mesh. For all of the other tests, Vacuum cleaner A was used with dust which had passed through a 250 micron mesh.

The steps followed in carrying out the work for each task listed in Section A1.1 are described in the following sections. In some cases, the test procedures were modified as the pilot tests progressed, or additional tests were performed which were not outlined in the original work plan. The following sections describe the tasks as they were conducted. If changes to the procedures in the original work plan were made during the progress of the pilot tests, they are noted in the description of each task.

A2.1 TASK 1 - Determine Stability of Tare Weights for New Clean Vacuum Cleaner Bags

Data on stability of the tare weight for new vacuum cleaner bags were observed by two different types of tests done on two different days. For Day 1, each of the four types of vacuum cleaner bags was weighed 10 times with at least half-hour intervals between

weighings. On Day 2, the bag used on Day 1 was inserted in the vacuum cleaner which was run for 1 minute (without actually vacuuming a surface). The bag was then removed and reweighed and the process repeated 10 times using the same bag. This procedure was carried out for all four vacuum cleaners. The specific procedure used on Day 1 and Day 2 is given below.

Day 1

- Weigh four different new vacuum cleaner bags 10 times each throughout the day, with at least half-hour intervals between weighings. Use one bag for each of the four different brands of vacuum cleaners.

- Record the weights, relative humidity (RH) and temperature (T) in the lab, and the time when weighings are made.

Day 2

- Run the vacuum cleaner for 5 minutes (without actually vacuuming a surface) with an old bag in place to purge loose dust.

- Discard the bag.

- Reweigh the bag from Day 1.

- Record RH and T and the time when weighed.

- Insert the tared bag into the vacuum cleaner and run the unit for 1 min (without actually vacuuming a surface).

- Remove the bag and weigh it.

- Repeat this vacuum procedure and weigh sequence 10 times for the same bag.

- Repeat this sequence of 10 weighings for each of four brands of vacuum cleaner bags.

Extra Test

Results from the Day 2 tests showed that the weight of Bag D was increasing over time as it sat on the scale. Therefore, an extra test was done as follows:

- Run vacuum cleaner for 40 seconds with new bag.

- Repeat above three times, 1 minute between, using same bag.

- Run vacuum cleaner 40 seconds.
- Immediately weigh bag, and record weight every 1 minute for 10 minutes.
- Repeat all the above once (total of two times).
- Repeat all the above for vacuum cleaners B, C, and D.

Because the sampling cassettes used for some of the samplers might also show weight changes over time, the following tests were also performed.

- Obtain a cassette which has been acclimated to room conditions for >24 hours (with the plugs removed).
- Weigh the cassette and record the weight every minute for 5 minutes.
- Remove the top half of the cassette and install the bottom half in the Blue Nozzle sampler.
- Run the sampler for 120 seconds.
- Remove the cassette and reinstall the top half.
- Weigh the cassette and record the weight every minute for 5 minutes.
- Repeat running the sampler and weighing the cassette once.
- Repeat all of the above with another cassette once.

A2.2 TASK 2 - Demonstrate Method of Securing Carpet and Upholstery Substrates for Testing Vacuum Cleaners

This task required construction of a 6-in high rectangular table designed to support and secure carpet, upholstery, and other substrates for vacuuming, in accordance with an ASTM method. The procedure for carrying out this task was:

- Construct a 6-in high rectangular table (1.83 m x 0.69 m) with the top made from 3/4-in thick exterior grade plywood (per ASTM Method F608-89). Provide a mechanism for securing carpet section, or upholstery section, at the corners of the table. The carpet section will include the pad underneath, and the upholstery will include a 1/2-in thick foam pad underneath.

- Determine suitability of table for vacuum cleaner tests by vacuuming a carpet section with the upright vacuum cleaner and with one of the canister vacuum cleaners. Similarly, vacuum an upholstery section with the same two vacuum cleaners using the proper attachments.

- Revise system for securing carpet or upholstery, if necessary, after approval by project leader.

A2.3 TASK 3 - Determine if Preconditioning Procedures are Feasible for Using New Carpet in the Laboratory Tests, and Determine if use of the Same Carpet for Each Series of Tests is Feasible

Task 3 consisted of a two-step process using vacuum cleaner A only. Step 1, preconditioning of carpet without dust, involved vacuuming the carpet section for 5 minutes followed by weighing the bag, and repeating this process 10 times. In step 2, which used the carpet section from Step 1, two different amounts of dust were applied to the carpet, with each amount being applied and followed by three 30-second vacuumings. Three sets of tests were done for each of the two amounts of dust. These three tests differed in that the vacuuming of the wand and brush was done in three different ways:

- After completing the entire test.

- After each set of three vacuumings within each test.

- After each vacuuming.

The multiple parts of Step 2 provided important data on the effect of vacuuming the wand and brush and on dust pickup efficiency, after the carpet had already previously been used (i.e., dust applied and vacuumed up).

The procedures used in Step 1 and in all six parts of Step 2 (a to f) are listed below.

Step 1

- Vacuum the entire area of the secured carpet for 5 min.

- Discard bag.

- Measure RH and T.

- Place a new tared bag in the vacuum cleaner; vacuum carpet again for 5 minutes.

- Reweigh bag.

- Repeat the 5-minutes vacuuming and weigh process 10 times using the same bag.
- Determine incremental weight gain for each vacuuming.

Step 2 (using the preconditioned carpet from Step 1)

2a. Tests using 0.678 g of dust:

- Vacuum the wand and brush before the initial test; discard bag.
- Place new tared bag in vacuum cleaner.
- Put 0.678 g of sieved dust (e.g., < 250 µm) on the test area (100 mg/ft^2).
- Vacuum for half a minute.
- Weigh the vacuum bag.
- Repeat the last two steps (vacuum and weigh) three times using the same bag.
- Repeat the last five steps (new bag, deposit dust, vacuum and weight three times) three times.
- After completing all the above tests and the last weighing, vacuum the wand and brush and reweigh the bag.

2b. Tests using 2.71 g of dust:

- Vacuum the wand and brush before the initial test; discard bag.
- Place new tared bag in vacuum cleaner.
- Put 2.71 g of sieved dust on the test are (400 mg/ft^2).
- Vacuum for half a minute.
- Weigh the vacuum bag.
- Repeat the last two steps (vacuum and weigh) three times using the same bag.
- Repeat the last five steps (new bag, deposit dust, vacuum and weight three times) three times.

- After completing all the above tests and the last weighing, vacuum the wand and brush and reweigh the bag.

2c. Tests using 0.678 g of dust (same as 2a, except more frequent vacuuming of wand and brush):

- Vacuum the wand and brush before the initial test; discard bag.
- Place new tared bag in vacuum cleaner.
- Put 0.678 g of sieved dust on the test area (100 mg/ft^2).
- Vacuum for half a minute.
- Weigh the vacuum bag.
- Repeat the last two steps (vacuum and weigh) three times using the same bag.
- After the third vacuuming and weighing, vacuum the wand and brush and reweigh the bag.
- Repeat the last six steps (new bag, deposit dust, vacuum and weight three times, vacuum wand) three times.

2d. Tests using 2.71 g of dust (same as 2b, except more frequent vacuuming of wand and brush):

- Vacuum the wand and brush before the initial test; discard bag.
- Place new tared bag in vacuum cleaner.
- Put 2.71 g of sieved dust on the test area (400 mg/ft^2).
- Vacuum for half a minute.
- Weigh the vacuum bag.
- Repeat the last two steps (vacuum and weigh) three times using the same bag.
- After the third vacuuming and weighing, vacuum the wand and brush and reweigh the bag.
- Repeat the last six steps (new bag, deposit dust, vacuum and weight three times, vacuum wand) three times.

2e. Tests with 0.678 g of dust, including vacuuming of wand and brush with each vacuuming of the carpet:

- Vacuum the wand and brush before the initial test; discard bag.
- Put new tared bag in vacuum cleaner.
- Put 0.678 g of sieved dust on the test area (100 mg/ft^2).
- Vacuum for half a minute.
- Use the vacuum hose to vacuum dust from the wand and brush.
- Weigh the vacuum bag.
- Repeat the above sequence (vacuum carpet, vacuum wand and brush, weigh bag) three times using the same bag.
- Repeat the last six steps (new bag, deposit dust, vacuum-weight-vacuum wand three times,) three times.

2f. Tests with 2.71 g of dust, including vacuuming of wand and brush with each vacuuming of the carpet:

- Vacuum the wand and brush before the initial test; discard bag.
- Put new tared bag in vacuum cleaner.
- Put 2.71 g of sieved dust on the test area (400 mg/ft^2).
- Vacuum for half a minute.
- Use the vacuum hose to vacuum dust from the wand and brush.
- Weigh the vacuum bag.
- Repeat the above sequence (vacuum carpet, vacuum wand and brush, weigh bag) three times, using the same bag.
- Repeat the last six steps (new bag, deposit dust, vacuum-weight-vacuum wand three times,) three times.

One of the three sets of vacuumings described in step 2a showed a noticeably lower dust pickup efficiency, and was done by a different operator. To test if this lower recovery was associated with differences between operators, an extra test was

performed in which the entire Step 2a was repeated twice, using a different operator for each repetition.

A2.4 TASK 4 - Determine the Amount of Dust Needed for the Tests

Tests carried out in Task 4 used the same carpet sample and the same vacuum cleaner (A) as in Task 3. Task 4 required applying and embedding two different amounts of dust. The dust was applied either in 10 separate applications and vacuumed after each application, or once followed by 10 vacuumings (e.g., 0.678 g applied and vacuumed 10 times, or 6.78 g applied once and vacuumed 10 times).

Two of the four tests done in Task 4 required determining of the weight of dust that could be recovered from the vacuum cleaner bag after the test had been completed. This was important, since at least 100 mg needed to be recovered for lead analysis. If that amount could not be recovered, it would be very difficult to determine the lead content of the dust collected by the vacuum cleaner. It was anticipated that the larger amount would yield recovery of 100 mg even if the smaller amount did not.

According to the original work plan and the data sheets in Section A6.0, the specific procedures for Task 4 involving carpet samples and vacuuming of dust from the wand and brush depend on the results from Task 3. Based on the preliminary analysis of the Task 3 results (see Section A4.3), the Task 4 tests used the same carpet sample for all tests and the wand and brush were not vacuumed as part of the test.

The procedures used in carrying out the tests for Task 4 are as follows.

a. Application of 0.678 g of sieved dust to test area, 10 times:

- Put new tared bag in vacuum cleaner. Record RH and T.
- Apply 0.678 g of dust and embed. Brush any dust that sticks to embedding tool back onto the carpet. If it appears that significant amounts of dust are lost or cannot be brushed back onto carpet, contact project leader before proceeding.
- Vacuum carpet for half a minute.
- Weigh bag.
- Repeat 10 times using the same bag (adding 0.678 g of dust each time, for a total of 6.78 g).
- Remove bag from vacuum cleaner and make sure that bag inlet is wide open (cut away any sealing flaps if necessary). Place opening of bag over top of tared beaker and tap on outside of bag to dislodge dust into beaker.

Determine weight of dust recovered, that could be used for lead analysis. Observe dust to determine if fibers from bag are present in the sample.

- Repeat the entire process in Step a once.

b. Application of 6.78 g of sieved dust to test area, once:

- Put new tared bag in vacuum cleaner. Record RH and T.
- Apply 6.78 g of dust to test area and embed.
- Vacuum carpet for half a minute.
- Weigh bag.
- Vacuum surface again, using the same bag, without adding any dust to the test area.
- Weigh bag.
- Repeat the vacuum and weigh process for a total of 10 times.
- Repeat the entire process in Step b once.

c. Application of 2.71 g of sieved dust to test area, 10 times:

- Repeat the entire process described in Step a using 2.71 g of dust rather than 0.678 g.

d. Application of 27.1 g of sieved dust to test areaÑonce:

- Repeat the entire process described in Step b using 27.1 g of dust rather than 6.78 g.

Note: After completing Steps a through d of Task 4, Step a was repeated twice with three applications of dust. The three dust applications were followed by either three vacuumings after last application of dust or by seven vacuumings, as suggested by Westat.

A2.5 TASK 5 - Develop and Demonstrate Method for Measuring Exhaust Emissions from Vacuum Cleaners

Work on this task involved fabricating a system to feed a specific quantity of dust (5 g) into the inlet of a vacuum cleaner over a specific period of time (5 min). It also involved fabrication of a sealed enclosure, suitable for all vacuum cleaners to be tested

(including upright), so that only the suction tube extended outside the enclosure. The enclosure was built so that all exhaust emissions discharged through one duct. The diameter of the exhaust duct was designed so that isokinetic sampling could be carried out near the center of the duct, with the sample directed to a particulate concentration monitor measuring dust emissions in $\mu g/m^3$. A pitot tube was used to determine the total gas flow rate in the duct, so that the dust emission rate ($\mu g/min$) and total emissions (μg) could be calculated.

The vacuum cleaner enclosure and dust feed system used for Task 5 are described in Appendix O of Volume II of this report. The enclosure and feed system were used to carry out three replicate tests for each of the four vacuum cleaners. The dust used in tasks 1 through 4 was sieved to obtain dust which passed through a 53 micron sieve for use in Task 5.

A procedure for conducting the vacuum cleaner exhaust emission tests as part of the full study had been prepared for the QAPjP. These procedures, described in Appendix O of Volume II, were used in the pilot tests with only minor changes.

Throughout each test the concentration of particulate in the exhaust duct was continuously monitored and recorded on a strip chart recorder. The particulate concentration monitor is based on the detection of near-forward scattered electro-magnetic radiation in the near-infrared (940 nm). The monitor was Model RAM-1 purchased from Monitoring Instruments for the Environment Inc. (MIE) in Billerica, Massachusetts.

The test procedures specified the following steps:

- Turn on the particulate monitor and strip chart recorder. Mark the date, time, and run number on the strip chart. Also identify each of the following steps on the strip chart, and record the time.

- Turn on the vacuum cleaner. Run for 1 minute.

- Turn on the turntable and lower the vacuum cleaner nozzle until it nearly touches the turntable.

- Continue running for 5 minutes, thereby removing all of the dust from the turntable (i.e., one revolution).

- Continue running for 1 minute, then stop the test.

- Remove the bag from the vacuum cleaner; wait 5 minutes, then record the weight of the bag.

- Repeat the test three times for each vacuum cleaner.

The original plan specified repeating the test twice for one vacuum cleaner. When the pilot test was performed, it was easy to test all of the vacuum cleaners, following the procedures which were planned for the full study.

A3.0 DATA COLLECTION

All pilot tests were conducted at MRI's laboratory according to the work plan for this study and the laboratory procedures previously described for Tasks 1 through 5.

A3.1 Pilot Test Data Collection

All weights (bags and dust samples) were determined using Mettler PM 1200 and PM 2500 balances which were checked for accuracy each morning using standard check weights. Ambient relative humidity and temperature in the laboratory were recorded for each test. Embedding of dust into carpet, when prescribed, was performed according to the protocol for grinding dust into carpet (Appendix C of Volume II). For each series of tests, data were recorded on forms developed for these tests. The data for each task are reproduced in Sections A6.1 through A6.5 for Tasks 1 through 5 data, respectively.

Several of the tests involved vacuuming a section of carpet without dust application. Other tests involved applications of dust followed by vacuuming. One section of carpet was used in all the tests, mounted with carpet pad underneath, on the 6-in high table described previously in Task 2. The carpet section (1.83 m x 0.69 m) was made of nylon, purchased locally.

The dust for the tests was obtained from vacuum cleaner bags collected by Westat and MRI and then sterilized. Dust from these bags was mixed together. The portion of dust which passed through the 250 micron sieve was used for Tasks 3 and 4. This dust was resieved using a 53 micron sieve, to provide dust for the exhaust tests.

In order to apply dust as evenly as possible onto the carpet test area (1.37 m x 0.46 m), the prescribed amount of dust was weighed in a beaker along with the 250-µm sieve. Dust in the beaker was then poured onto the sieve over the test area, and the sieve lightly tapped as it was moved around above the test area. Most, but not all, of the dust passed through the sieve when using this method. Therefore, the sieve and beaker were subsequently reweighed to determine, by difference, the weight of dust that actually passed through the sieve onto the carpet test area.

A3.2 Quality Assurance Activities

The data sets from each task were audited for accuracy of weight data, balance calibrations, calculations, etc. In addition, a systems audit was conducted during the pilot study phase of this project.

A4.0 STATISTICAL DATA ANALYSIS

The statistical analyses of the pilot test data were performed by Westat.

A4.1 Analysis of Task 1

Stability of Tare Weights For New Vacuum Cleaner Bags (Task 1, Day 1)

Four bags, one from each of the four vacuum cleaners, were weighed at half-hour intervals. Measurements of temperature and relative humidity were recorded at the time of weighing.

Prior to the tests, it was suspected that the weight of a vacuum cleaner bag would change with a change in the relative humidity or temperature. Plots of the data showed a change in the bag weights over time where the rate of change was greatest in the beginning of the test. Although the trend in the weights might be associated with the fluctuations in the room temperature or relative humidity at the time of measurement, it might also result from the bag coming into equilibrium with the surrounding laboratory environment during the test and after it was removed from its storage area. If the rate at which the bag weight changes as it comes into equilibrium with the laboratory environment is proportional to the difference in the bag weight and the equilibrium bag weight, the bag weight will follow a simple exponential decay relationship. The difference between the bag weight at the beginning of the test and that at reaching equilibrium may be due to differences in temperature and relative humidity between the laboratory and the bag storage area.

In order to identify whether temperature, humidity, or approach to equilibrium provides the best explanation of the weight changes, a model was fit to the data with the terms for (1) a liner relationship between the bag weight and temperature, (2) a linear relationship between the bag weight and relative humidity, and (3) an exponential decay for the return to equilibrium. Nonlinear regression was used to fit the model. The regression parameters were used to identify which factors were most influential in determining the bag weight The root mean square error estimates the standard deviation of one measurement. The equation to fit the data was:

$$\text{Bag weight} = C + R*(\text{Relative humidity}) + T*\text{Temperature} + D * (1 - \exp(-(\text{time})/M))$$

where:

Bag weight is measured in grams.

Relative humidity is measured in percent.

Temperature is measured in degrees Fahrenheit.

Time is measured as the number of minutes from the time of the first measurement.

C = a constant (the initial weight of the bag, in grams, at 0% relative humidity and 0 degrees Fahrenheit).

R = the change in the bag weight, in grams, associated with an increase in the relative humidity of 1%.

T = the change in the bag weight, in grams, associated with an increase in the temperature of one degree Fahrenheit.

D = the change in the bag weight, in grams, from the beginning of the test to until equilibrium is reached.

M = the equilibration time of the bag, the time, in minutes, for the bag weight to reach 69% of equilibrium.

This model was fit to the data for each vacuum bag tested. The parameter estimates and the root mean square error are shown in Table A-1. Following the table, for each vacuum cleaner bag, Figure A-1 shows the weight measurements (using circles), the predicted weights (using diamonds), and the predicted weight change (trend) associated with the bag coming into equilibrium with the laboratory environment. The differences between the trend and the model prediction are due to changes in the temperature and relative humidity during the tests.

For all four vacuum bags, the estimated weight changes associated with an approach to equilibrium were statistically significant. The estimated weight changes associated with changes in temperature were not statistically significant. The estimated weight changes associated with changes in the relative humidity were statistically significant for bags from vacuums B, C, and D.

The importance of trend, temperature, and relative humidity in determining the precision of the bag weight depends on the changes in time, temperature, and relative humidity which might be expected during the test. During the pilot tests the temperature and humidity were fairly stable over short periods of time. Assuming that fluctuation in temperature and relative humidity are similar during the full tests to those during this pilot test, and assuming further that the bag weights are close to equilibrium, the root mean square error measures the standard deviation of a single weight measurement. These estimates are shown in Table A-1.

Table A-1 Regression estimates for predicting the weight of vacuum cleaner bags as a function of time, relative humidity, and temperature for data collected on Day 1.

Parameter		Vacuum			
		A	B	C	D
C	Constant	**35.5**	**42.0**	**30.2**	**41.0**
R	Change in weight with change in relative humidity (g/%RT) with 95% confidence intervals	0.003 -.003 to 0.009	**.0.013** 0.001 to 0.024	**0.006** 0.002 to 0.010	**0.007** 0.003 to 0.011
T	Change in weight with change in temperature (g/^{o}F) with 95% confidence intervals	-.005 -.022 to 0.012	.003 -.409 to 0.362	.003 0.12 to 0.012	.003 -0.10 to 0.010
D	Difference between initial weight and equilibrium weight (g)	**0.023**	**0.048**	**0.014**	**0.017**
M	Equilibrium time in minutes with 95% confidence intervals	**29.7** 7.8 to 112.9	**43.0** 12.7 to 145.7	**109.3** 23.6 to 505.8	**24.3** 6.7 to 88.5
Root mean square error (g)		0.0034	0.0064	0.0018	0.0023

Model: Bag weight = C + R * (Relative humidity) + T * Temperature + D * (1 - exp(-(time)/M))
Statistically significant results are shown in bold text

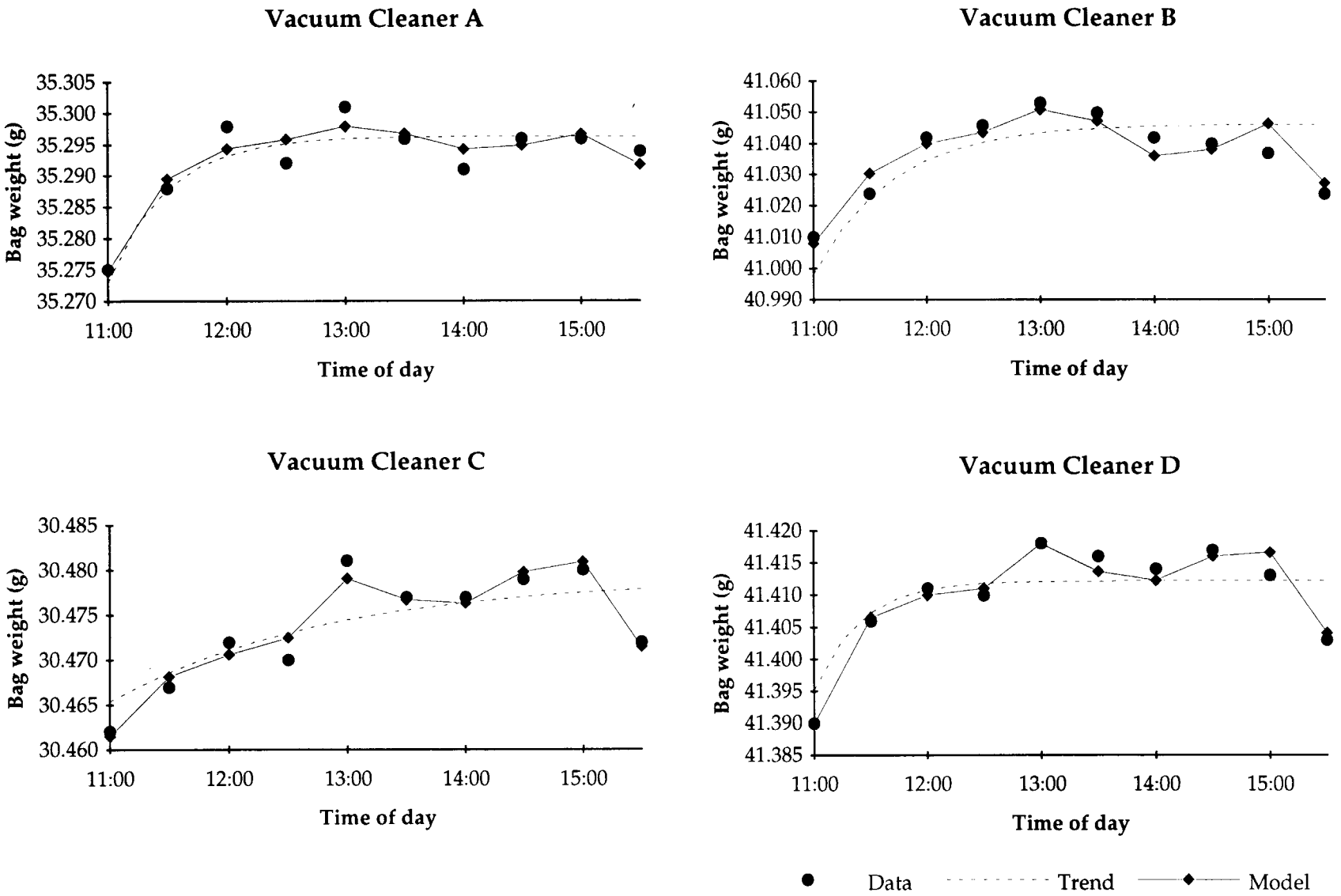


Figure A-1 Measured and predicted weights of vacuum cleaner bags over time from Day 1

Recovery measurements are based on the change between the initial and final weight of the vacuum cleaner bag. The standard deviation for this change is 1.414 (sqrt(2)) times the standard deviation of one weight measurement. Further, assuming that accurate weight change measurements can be achieved if the weight change is 10 times the standard deviation of the weight change measurements, the weight changes would need to be roughly 14 times the root mean square error shown in Table A-1. For the largest root mean square error in Table A-1, 0.0064, the standard deviation (i.e., 0.091 grams) could therefore be measured with acceptable precision. The precision would be better for some vacuum cleaners than for others.

The estimates of the equilibration times have implications for the how long the bags should sit before making weight measurements. These values will be discussed later.

Stability of Tare Weights for Vacuum Cleaner Bags Placed in the Vacuum (Task 1, Day 2)

During Day 2, our bags, one from each of the four vacuum cleaners, were weighed 10 successive times. Each weighing was separated by placing the bag into the vacuum cleaner and running the vacuum for 1 minute. Measurements of temperature and relative humidity were recorded at the time of weighing. The model fit to this data is the same as fit to the data from Task 1, Day 1. Table A-2 and Figure A-2 present the results from fitting the model to the data for each vacuum.

When weighing unused bags on Day 1, the weight increased over time as the bags came into equilibrium However, when putting the bags into the vacuum and running the vacuum, the weight decreased over time.

Based on the root mean square error, weight changes of 0.100 grams would have acceptable precision for all the vacuum cleaners. This estimate is similar to that from the measurements on Day 1.

The equilibrium time estimates for the data from Day 1 and Day 2 are similar. That is, it takes about 30 minutes for the bag weight to go 69% of the way to its equilibrium weight. This time is similar whether or not the bag is placed in the vacuum and run for a minute. Unless the laboratory staff waits a long time for the bag weight to come to equilibrium, the weight measurement will depend on the time at which the weight is taken.

It was decided to standardize the time between removing the bag from the vacuum and the weight measurement for subsequent tests to control the weighing error. For Tasks 3 and 4, the time between vacuuming and weighing was 5 minutes, timed with a stop watch.

Table A-2 Regression estimates for predicting the weight of vacuum cleaner bags as a function of time, relative humidity, and temperature for data collected on Day 2.

Parameter		Vacuum			
		A	B	C	D
C	Constant	**40.1**	**45.9**	**29.9**	**49.5**
R	Change in weight with change in relative humidity (g/%RT) with 95% confidence intervals	0.034 -.096 to 0.029	**-.037** 0.064 to 0.011	0.003 -0.22 to 0.016	-0.32 -.121 to 0.058
T	Change in weight with change in temperature (g/^{o}F) with 95% confidence intervals	-.039 -.108 to 0.029	**-0.39** **-.064 to -.015**	.006 -.013 to 0.025	**-.191** **-.284 to -.097**
D	Difference between initial weight and equilibrium weight (g)	**-.109**	**-.104**	**-0.20**	**-.226**
M	Equilibrium time in minutes with 95% confidence intervals	**30.3** 16.3 to 44.2	**30.1** 24.5 to 35.6	**25.8** 6.2 to 45.3	**16.8** 13.7 to 20.0
Root mean square error (g)		0.0042	0.0027	0.0020	0.0071

Model: Bag weight = C + R * (Relative humidity) + T * Temperature + D * (1 - exp(-(time)/M))
Statistically significant results are shown in bold text.

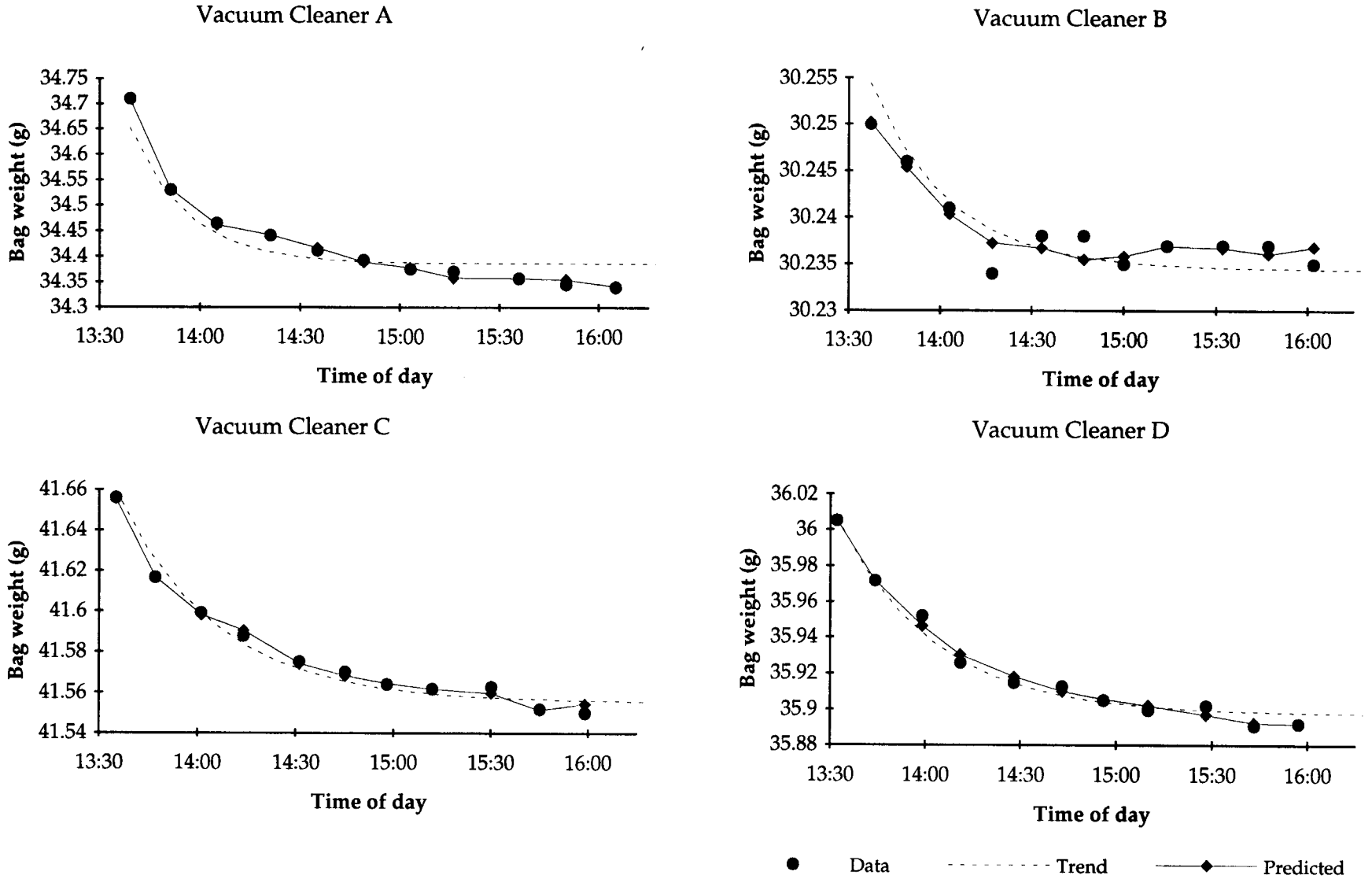


Figure A-2 Measured and predicted weights of vacuum cleaner bags over time from Day 2

Although the time between vacuuming and weighings was 5 minutes for Tasks 3 and 4, a question arose about the best time to use in the full study. To answer this question, extra tests were performed to measure the weight change over time after removing the bag from the vacuum. These tests were done using two bags for each of the four vacuums. Similar tests were performed for the sampling cassettes used for the Blue Nozzle vacuum sampler, testing two cassettes twice each. The results of these extra tests are discussed below.

The exponential decay model: Bag weight - C + D * (1 - exp(-(time)/ M)) was fit to the measurements from the extra tests using nonlinear regression.

Waiting for the bags to reach equilibrium might add considerable time to the test process. An alternative is to specify a fixed time between the removal of the bag from the vacuum and weighing (call this the time after vacuuming), thus standardizing the weighing procedure. When specifying a fixed time after vacuuming for the weighing, the precision of a weight measurement depends on the rate at which the weight is changing and the precision with which the time after vacuuming can be set. Assuming that the actual time between vacuuming and weighing varies around the proscribed time and has a standard deviation of 5 seconds, the variance of the weight is equal to the mean square error plus the error associated with timing (the rate of weight change times the variance of the time after vacuuming). Using these assumptions, the standard deviation of a weight measurement is shown in Figure A-3 for each of the vacuum cleaner bags tested and in Figure A-4 for each of the sampling cassette tests.

For both the sampling cassettes and the vacuum cleaner bags, the standard deviation of one weight measurement decreases with increasing time between turning the vacuum off and weighing the bag. However, except for the bags from vacuum cleaner D, there is little improvement in precision beyond the first several minutes.

A4.2 Analysis of Task 2

No data was generated for analysis of Task 2.

A4.3 Analysis of Task 3

Task 3 consisted of (1) fiber preconditioning of a test piece of carpet to determine how much effort was required to precondition the carpets and (2) tests to determine if there was significant carryover of dust from test to test and how much dust adhered to the vacuum cleaner wand and brush during vacuuming.

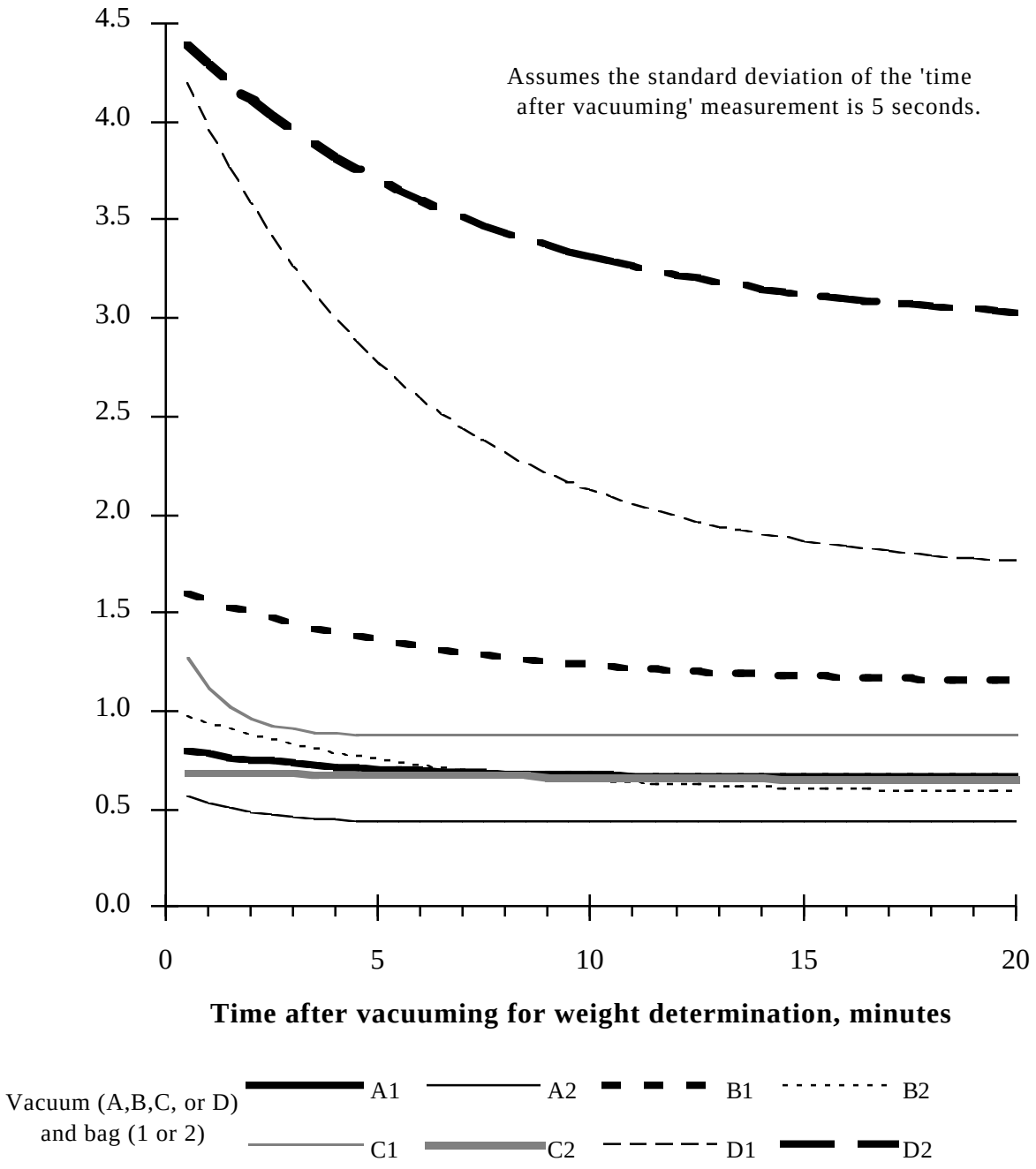


Figure A-3 Standard deviation of one vacuum cleaner bag weight measurements as a function of equilibration time

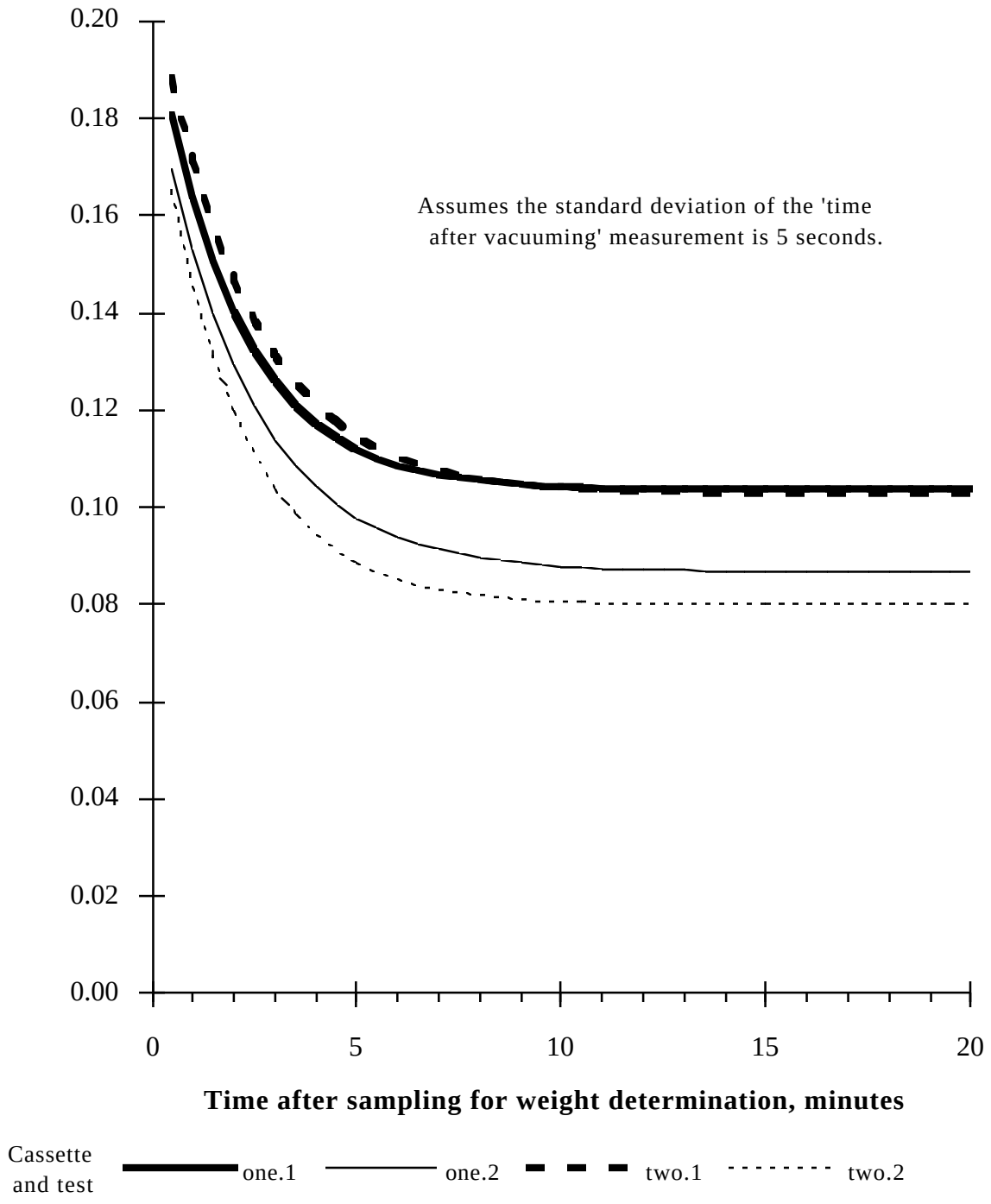


Figure A-4 Standard deviation of one cassette weight measurement as a function of equilibration time

Fiber Preconditioning

For the fiber preconditioning tests, a piece of carpet was vacuumed 11 times, each time for 5 minutes. The first vacuuming was used to warm the vacuum cleaner, after which the weight increase in the bag was measured for each of the 10 vacuumings. The weight of the bag was determined after the bag had been on the balance for 5 minutes. The weights were clearly increasing at the five-minute point. Therefore, after the 11th vacuuming, additional bag weights were obtained to determine the rate of change in the bag weight with time, in the absence of vacuuming.

The weight increase of the vacuum bag due to fibers removed from the carpet for each successive vacuuming is shown in Figure A-5. For this sample of carpet used in the pilot studies, the additional fiber collected for each 5 minutes of vacuuming decreased to below 0.500 grams after two vacuumings (or equivalently after 10 minutes of vacuuming) and below 20 milligrams after six vacuumings, or equivalently, after 30 minutes of vacuuming. When developing the pilot study protocols, it was decided that weight gains from fibers of more than 100 milligrams per minute would be unacceptable and provide too much bias in the measurements. This level of weight increase due to fibers was obtained in only 10 minutes of vacuuming. However, the data also suggested that, with about 30 minutes of vacuuming, the fibers vacuumed could be kept to a low level which would have little effect on the recovery measurements and would vary little from test to test. Assuming that similar amounts of fibers were vacuumed from other carpet samples, a target of 20 milligrams per 5 minutes of vacuuming was set for the fiber preconditioning.

The additional measurements of the weight of the vacuum bag collected after the last vacuuming were analyzed. The equilibrium time was estimated to be 21 minutes, in the same general range as determined using the data from Task 1.

Dust Recovery

For the dust recovery pilot tests, either 0.678 grams or 2.71 grams (approximately) of dust were applied to the carpet, after which the carpet was vacuumed three times for 40 seconds each time. The dust recovery was measured for each of the vacuumings. A total of 18 tests were performed, six sets of three tests each. For the first two sets of three tests, the amount of dust on the vacuum wand and brush was measured at the end of the set. For the second two sets of three tests, the amount of dust on the vacuum wand and brush was measured at the end of the test. For the last two sets of three tests, the amount of dust on the vacuum wand and brush was measured after each vacuuming of the carpet and thus the dust on the wand and the brush was included into the estimate of dust vacuumed. Within each set of two tests, the first test used nominally 0.678 grams of dust and the second used 2.71 grams of dust. For each test, the recovery was calculated as the ratio of the amount of dust deposited to the weight increase in the bag summed across the three vacuumings.

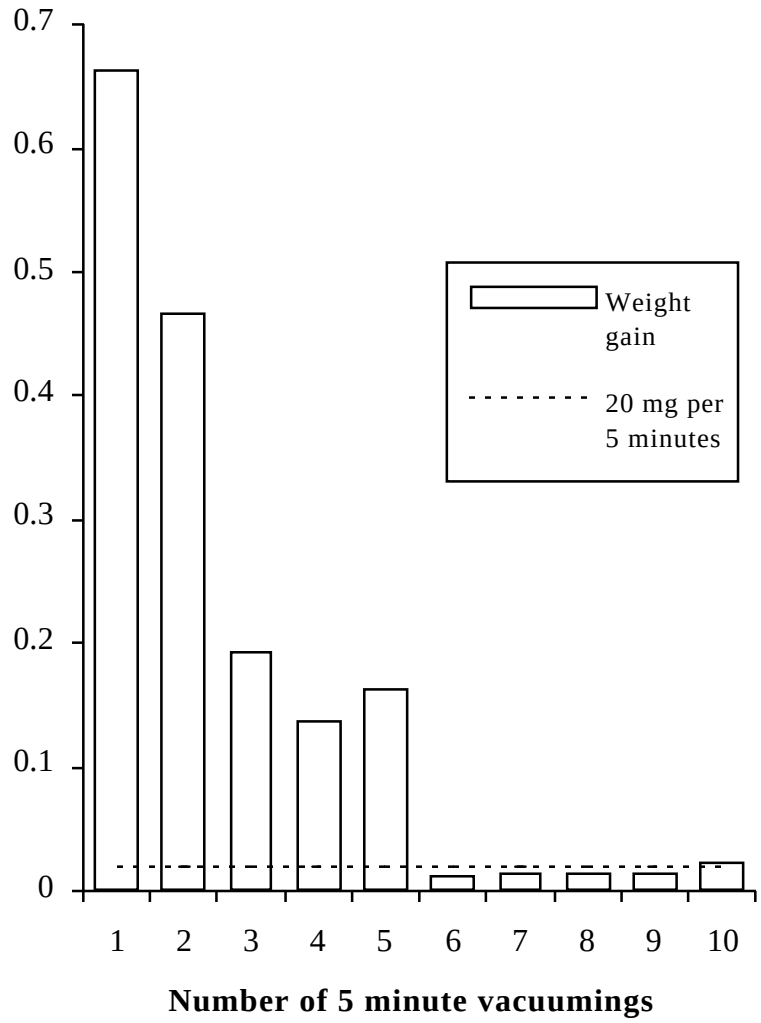


Figure A-5 Weight increase of vacuum bag during fiber preconditioning

Figure A-6 shows both a histogram and a time series plot of the recovery measurements. The time series plot shows the recovery for the tests in the order they were conducted, going from top to bottom. Along the left axis a bar graph shows the relative amounts of dust deposited for each test. The recovery measurement for the second test is noticeably different from the other measurements and is classified as an outlier by standard outlier tests. One possible explanation for this unusual observation is that this test was performed by a different lab technician than the other tests in Task 3. The recovery measurements for the first tests appear to be more variable than for later tests. There may be an associated learning time in which the technicians learned to perform the tests consistently. The analysis of the data was performed both with and without the outlier.

Analysis of variance was used to identify factors which affect the recovery. The factors considered included the test procedure for vacuuming the wand and brush, the amount of dust deposited, and the interaction of these factors. Other terms were included to test for carryover of dust from one test to the next and to test for trends over time. No factors were statistically significant at the five percent level. This was true whether or not the outlier was included in the analysis. Thus, there is no evidence that the procedure for vacuuming the wand and brush affect the recovery estimates. There is also no evidence of a trend across the three tests within each set that might suggest that dust carries over from one test to another.

Since no factors appear to affect the recovery, the measurements are summarized here by their mean and confidence intervals. The mean recovery over all tests is 85.3% with a 95 percent confidence interval from 82.1% to 88.5%. With the outlier removed, the mean recovery is 86.7% with a confidence interval from 85.3% to 88.1%. In either case, the recovery is relatively high. This recovery on carpet is expected to be lower than for all other substrates except carpet with ground in dust.

The standard deviation of the recovery measurements is 6.5% with the outlier included and 2.7% it excluded. These precisions for measuring recovery are well within the requirements for meeting the data quality objectives for the study.

Measurements of the dust collected on the wand and brush were obtained for two of the test procedures. The average amount of dust removed from the wand and brush by vacuuming, as a percentage of the dust deposited since the wand and brush were last cleaned, was 0.19% when the wand and brush were cleaned after each set of three tests and 0.44% when the wand and brush were cleaned after each test. The largest measurement of dust vacuumed from the wand and brush was 0.71% of that deposited.

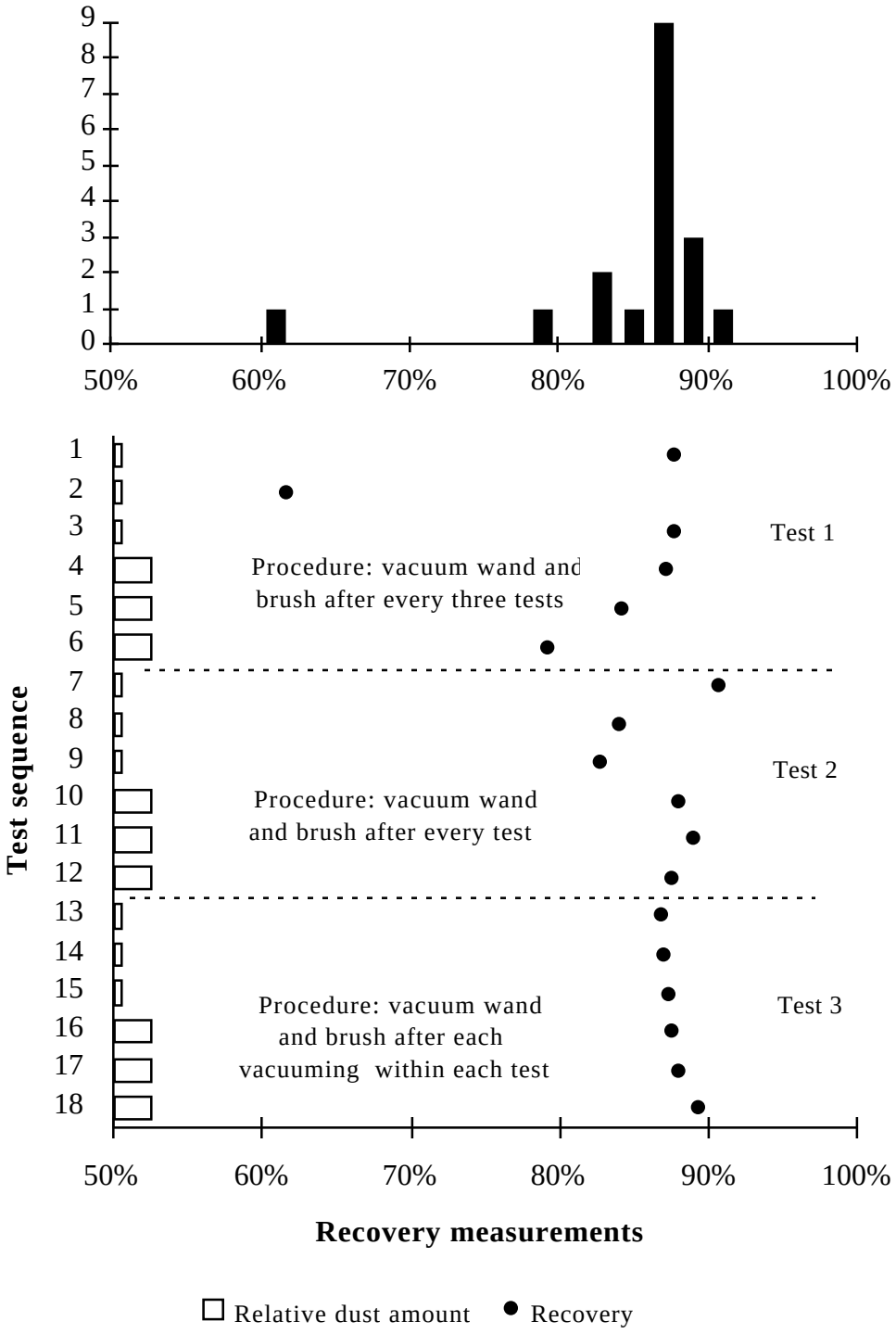


Figure A-6 Histogram and time series plot of recovery measurements for Task 3

The amount of dust removed from the wand and brush was consistently less than 1% of the dust deposited. Any differences in the recovery measurement due to the procedure used to vacuum the wand and brush were too small to be identified in the statistical analysis. Due to the time required to vacuum the wand and brush and to the small amount of dust collecting on the wand and brush, it was decided not to vacuum the wand and brush as a part of each test. In addition, due to the relatively long time required to precondition each carpet sample (at least 10 minutes) and the lack of evidence for carryover of dust from one test to another, it was decided to use the same carpet sample for all tests in Task 4 rather than preconditioning a new carpet sample for each test.

A4.4 Analysis of Task 4

In Task 4, tests with different amounts of dust applied in either 1 or 10 applications were used to help determine how much dust was needed to get a measurable amount in the vacuum bag and a usable amount from the bag for lead analysis. These tests used the conditions with the lowest expected dust recovery, carpet with ground-in dust. In the first two tests, the 0.678 grams or 2.71 grams of dust were applied 10 times, followed each time by vacuuming for 30 seconds. In the second two tests, 6.78 grams and 27.1 grams of dust were applied once, followed by 10 successive vacuumings. For each vacuuming, the weight increase in the vacuum cleaner bag was determined. For each test, dust was removed from the vacuum cleaner bag and weighed to determine if the amount of dust obtained was adequate for the laboratory analysis of lead.

The preliminary results from Task 4 suggested that three dust applications followed by three more vacuumings, would provide good estimates of recovery and enough dust for measuring the lead concentration and would result in little carryover of dust from test to test. An extra series of tests was conducted to determine if this preliminary design would indeed meet these objectives.

The results from the first set of three tests in Task 3 suggested that the vacuum cleaner operator could make a significant difference in the recovery measurement. An extra test was performed repeating this first set of tests with each of two operators. The dust was not ground in for these tests or for the other Task 3 tests.

Rather than analyze the data from Task 4 by itself, the data from Task 3, Task 4, and the extra tests with three dust applications and the repeat of the Task 3 set of tests were combined to create a complete history of the dust deposited and dust vacuumed from the one carpet sample used in the pilot tests. The combined data was analyzed to identify factors which affect recovery and to provide a model for dust recovery that can be used as a basis for establishing the final design for the main tests.

Figure A-7 shows the amount of dust applied before and the amount of dust recovered for each of the 168 half-minute vacuumings of the carpet after the completion of fiber preconditioning. For each of the vacuumings, the vertical black bar in Figure A-7

indicates the increase in the bag weight due to dust and fibers removed from the carpet. If dust was applied to the carpet immediately before vacuuming, the top of the white vertical bar indicates the weight of the dust applied. In all but one case was greater than the weight of dust and fibers removed.

The model fit to the data assumes that a fixed percentage of the dust deposited is picked up during the first 30 second vacuuming. Of the dust that remains on the carpet, a different fixed percentage is picked up during the second vacuuming, and so on for subsequent vacuumings. Some of the dust may not be removed by vacuuming, and thus the dust amounts removed may equal less than the dust amounts deposited. This general model can be fit to the data using regression. The model can be written as:

$$\text{Weight of dust removed} = a + b1X1 + b2X2 + b3X3 + \ldots$$

Where the following process is assumed to have occurred:

(1) An amount of dust X3 is deposited.

(2) The carpet is vacuumed for 30 seconds.

(3) An amount of dust X2 is deposited.

(4) The carpet is vacuumed for 30 seconds.

(5) An amount of dust X1 is deposited.

(6) The carpet is vacuumed for 30 seconds and the weight of the dust caught in the bag is Y.

The model assumes that the vacuum bag captures a fraction b1 of the dust X1, a fraction b2 of the dust X2, a fraction b3 of the dust X3, a fraction of dust deposited before the X3 deposit, and a small quantity a, which might be fibers or dust from other sources.

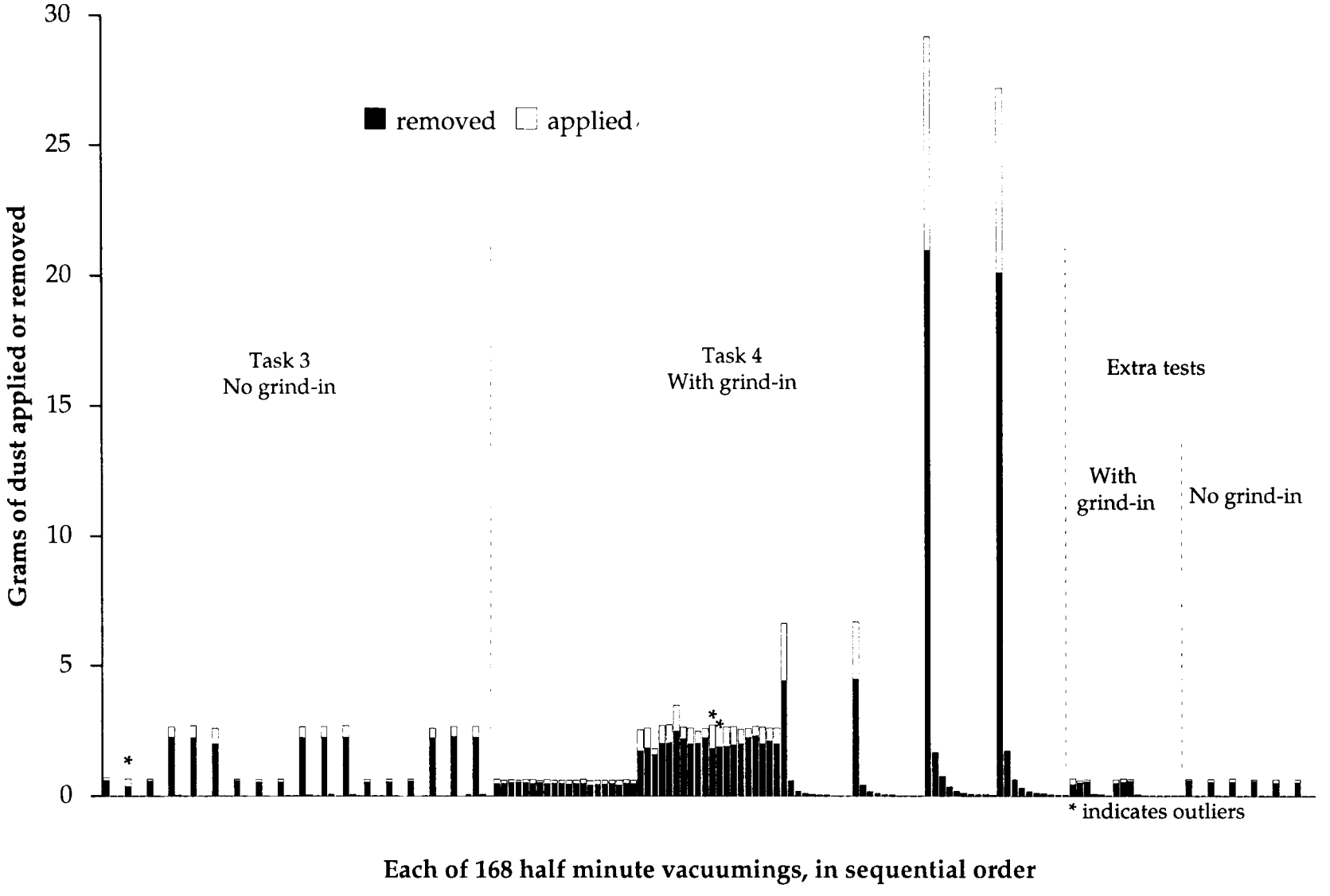


Figure A-7 Time series plot of dust applied and dust removed from the carpet samples in Tasks 3 and 4

Additional terms were added to this model to account for the following effects:

- Different proportions of dust being picked up on the first vacuuming when different densities of dust are deposited.
- Effects associated with temperature and relative humidity and changes in temperature and relative humidity.
- Trends over time.
- Differences associated with the test protocols.

The final model fit to the data was:

$$Y = a + b_{11}*X_{11} + b_{12}*X_{12} + b_2*X_2 + b_3*X_3 + b_4*X_4 + b_5*X_5 + b_{6\text{-}10}*X_{6\text{-}10} + b_{11\text{-}20}*X_{11\text{-}20} + g11*Z_{11} + g12*Z_{12} + g13*Z_{13} + g14*Z_{14} + g2*Z_2 + g3*Z_3 + g4*Z_4 + g5*Z_5 + g6\text{-}10*Z_{6\text{-}10} + g11\text{-}20*Z_{11\text{-}20} + r_1*RH + r_2*Temp + r_3*DRH + r_4*DTemp + t*obs + p_{i(i=1,7)} \quad [1]$$

where:

Y = the change in the dust weight during 30 seconds of vacuuming.

a = a constant.

X_{11} = the amount of dust which was deposited at a loading of 100 mg/sq.ft. prior to vacuuming

b_{11} = the proportion of dust which was deposited at a loading of 100 mg/sq.ft. which was picked up on the first vacuuming.

X_{12} = the amount of dust which was deposited at a loading of 400 mg/sq.ft. prior to vacuuming

b_{12} = the proportion of dust which was deposited at a loading of 400 mg/sq.ft. which was picked up on the first vacuuming.

X_2 = the amount of dust deposited two vacuumings prior to the end of the present vacuuming. Similar definitions apply to X3, X4, etc.

b_2 = the proportion of dust amount X2 which contributes to Y, similarly for b3 and X3, b4, and X4 etc.

$X_{6\text{-}10}$ = the total amount of dust deposited between the sixth and tenth vacuuming prior to the present vacuuming. Similar definitions apply to X11-20.

$b_{6\text{-}10}$ = the proportion of dust amount X6-10 which contributes to Y. Similar definitions apply to b11-20.

g_{11} = the proportion of dust deposited and ground in at 100 mg/sq.ft. picked up on the first vacuuming.

Z_{11} = the amount of dust deposited and ground in prior to vacuuming at a loading of 100 mg/sq.ft.

g_{12} = the proportion of dust deposited and ground in at 400 mg/sq.ft. picked up on the first vacuuming.

Z_{12} = the amount of dust deposited and ground in prior to vacuuming at a loading of 400 mg/sq.ft.

g_{13} = the proportion of dust deposited and ground in at 1,000 mg/sq.ft. picked up on the first vacuuming.

Z_{13} = the amount of dust deposited and ground in prior to vacuuming at a loading of 1,000 mg/sq.ft.

g_{14} = the proportion of dust deposited and ground in at 4,000 mg/sq.ft. picked up on the first vacuuming.

Z_{14} = the amount of dust deposited and ground in at a loading of 4,000 mg/sq.ft.

Z_2 = the amount of dust deposited and ground in two vacuumings prior to the end of the present vacuuming. Similar definitions apply to Z3, Z4, etc.

g_2 = the proportion of dust amount Z2 which contributes to Y, similarly for g3 and Z3, g4, and Z4 etc.

RH = the relative humidity as a percent.

r_1 = the effect of relative humidity on the weight gain measurement.

Temp = the temperature in degrees Fahrenheit.

r_2 = the effect of temperature on the weight gain measurement.

DRH = the change in relative humidity from the previous to the current weight gain measurement.

r_3 = the effect of changes in relative humidity on the weight gain measurement.

DTemp = the change in the temperature from the previous to the current weight gain measurement.

r_4 = the effect of changes in temperature on the weight gain measurement.

obs = the number of the vacuuming, 1 to 168, provides a measure of time.

t = the effect of time, as measured by the number of observations, on the weight gain measurement.

$p_{i(1=1,7)}$ = a classification variable used to indicate the test procedure used.

The model has many terms which, in the end, turned out to be insignificant. Because the objective of the modeling effort was to identify factors which affected the weight gain measurement, rather than to fit a specific model or to identify a parsimonious model for prediction, all terms which were initially thought important were included.

A preliminary analysis indicated that the measurement variance was a function of the weight of dust removed. Weighted regression was used to fit the data, where the regression weights were proportional to the inverse of the estimated measurement variance. The regression weights were determined based on the following analysis. The log of the absolute value of the residuals is proportional to the log of the standard deviation of the residuals. During the investigation of the variance of the residuals, it was noted that the log of the absolute residuals were linearly related to the log of the predicted values from the regression. This suggested that the following model might be used:

$$\text{Ln(Abs(residuals)+0.001)} = c + d*\text{Ln(predicted+0.001)} \qquad [2]$$

The small value of 0.001 was used to make the distribution of the values closer to normal and to reduce the influence of values which were very close to zero, perhaps by chance. Using this model, the weights for regression were:

$$\text{Wgt} = 1/(\exp(c + d*\text{Ln(predicted+0.001)})^{\wedge}2 \qquad [3]$$

Because the predicted regression weights depend on the model fit to the data and the regression weights used to fit the model, the following iterative procedures were used to calculate the regression weights used in the final analysis:

(1) fitting the model (1) to the data using unweighted regression, saving the residuals and predicted values.

(2) fitting model (2) to the residuals and predicted values using regression and using the parameters to define the preliminary regression weights using equation (3). Using the unweighted regression, some predicted values were negative. In this case 0.02 rather than 0.001 was added to the predicted values before taking the log.

(3) fitting the model (1) to the data using weighted regression, saving the residuals and predicted values.

(4) identifying three outliers and fitting model (2) to the residual and predicted values without using the outliers and using equation (3) to calculate provisional regression weights.

(5) fitting the model (1) to the data without the outliers using weighted regression, saving the residuals and predicted values.

(6) fitting model (2) to the residual and predicted values without using the outliers and calculating the final regression weights using equation (3) where the predicted values in equation (3) come from the regression in step (5) except for the outliers in which the predicted values from the regression in step (3) are used.

Plots indicated that the procedure for calculating the regression weights had equalized the variance of the weighted residuals. The regression weights varied substantially, with the ratio of the largest to smallest weight being about 8,000. The large variation in the regression weights indicates the importance of using weighted regression.

The equation for the regression weights and the regression output was used to calculate the coefficient of variation of one weight gain measurement as a function of the magnitude of the weight gain in the vacuum cleaner bag during a 30-second vacuuming. This relationship is shown in Figure A-8. Assuming that the amount of dust applied can be measured with relatively little error, the coefficient of variation of the recovery measurement is the same as for the weight gain in the bag. Assuming that the weight gains from each of three successive vacuumings are statistically independent, the coefficient of variation of the weight gain summed across three vacuumings was also calculated and is plotted in Figure A-8.

The assumption that three successive weight gains are independent is probably not true. However, there is no evidence from the data to support a lack of independence. Nonetheless, the estimated coefficient of variation for weight gain from three vacuumings should be considered approximate.

The model (equation (1)) provided a very good fit to the data, explaining over 99% of the variance in the weight gain measurements. The only factors which were statistically significant at the 5 percent level were those associated with the deposit of dust and the deposit and grind-in of dust. No effects of temperature, relative humidity, time, or test procedures were significant. After fitting the full model, additional terms were added to determine if there were differences between operators, if the residuals were significantly correlated, and if the change over time might be represented better by a quadratic rather than a linear relationship. None of these tests gave statistically significant results.

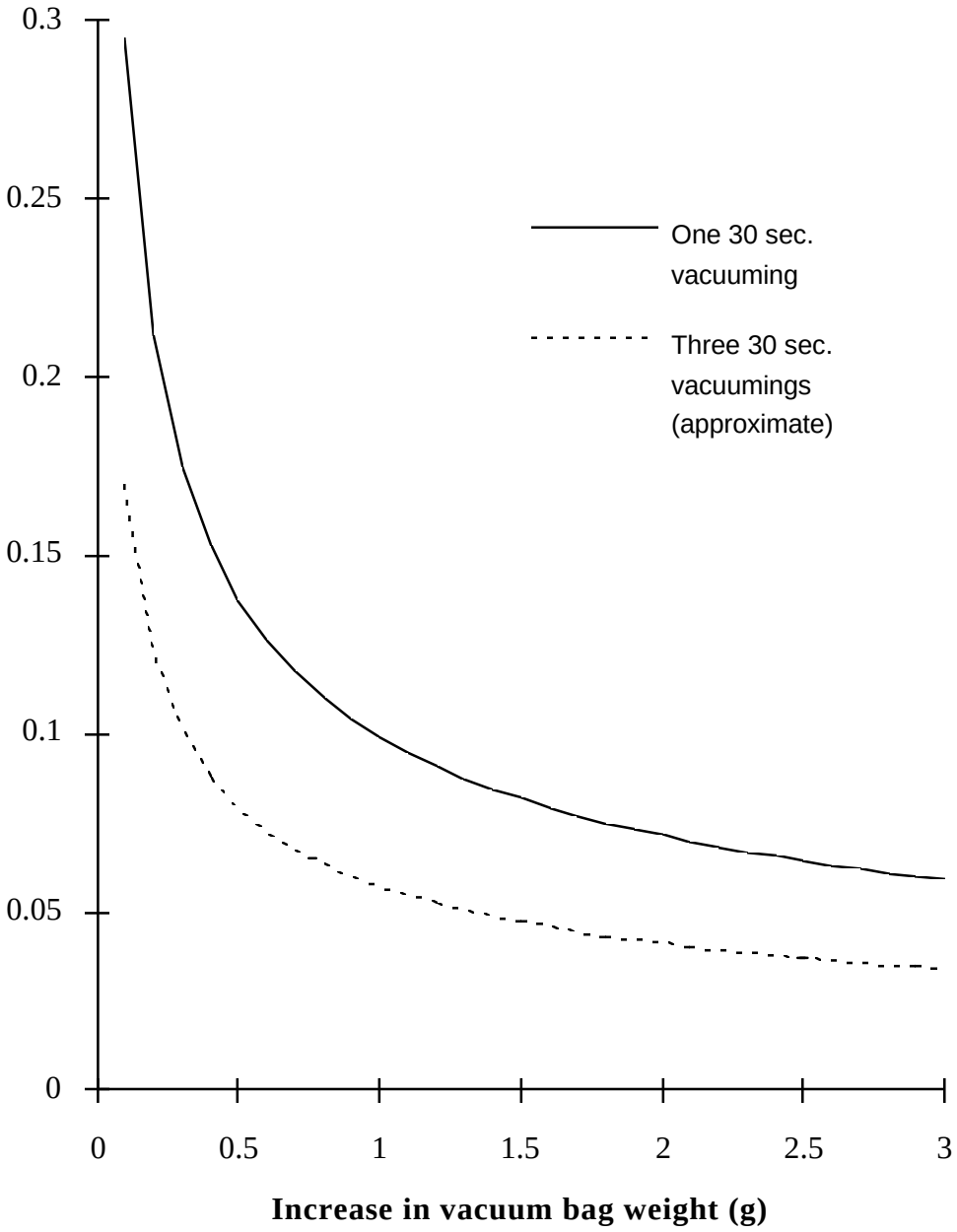


Figure A-8 Estimated coefficient of variation of the weight change of a bag from vacuum cleaner A as a function of the weight change

Based on the parameter estimates from the model, the recovery, in each successive 30 seconds of vacuuming, of dust deposited, or deposited and ground in, at a loading of 100 mg/ sq.ft. is shown in Figure A-9. As can be seen in this figure, most of the dust is recovered on the first vacuuming, with significantly reduced amounts collected on each successive vacuuming. Compared to recovery for ground-in dust, recovery for dust deposited on the carpet without any grind-in is greater for the first vacuuming which picks up the loosest dust and significantly less for subsequent vacuumings. The ground-in dust is more difficult to remove on the first vacuuming, leaving more dust for removal on subsequent vacuumings.

Figure A-10 shows the recovery versus vacuuming effort using a log scale. The shape of the curve suggests that the dust might be considered to have three components, loose dust which is removed entirely in the first vacuuming, dust which is gradually removed in successive vacuumings, and dust which is either not removed using the vacuum cleaner or is otherwise lost from the carpet. The change in the recovery with increasing vacuuming effort suggests that after the first vacuuming, each successive vacuuming removes about half of the dust which can be removed using the vacuum. This suggests that, for dust which is just deposited on the carpet surface, roughly 16% is either not collected by the vacuum or is otherwise lost, 4% is caught in the carpet (of which half is removed with each 30 seconds of vacuuming) and the remaining 80% is loose dust which is removed on the first vacuuming. For dust which is ground in, these numbers are, 21% that is either not collected or otherwise lost, 12% that is caught in the carpet (of which half is removed with each 30 second vacuuming) and the remaining 68% that is loose and is removed on the first vacuuming. Figure A-10 shows the slope of the relationship between recovery and vacuuming effort which corresponds to vacuuming 47% of the remaining dust which can be vacuumed on each successive 30 seconds of vacuuming.

The estimated cumulative dust recovery after many vacuumings is 84% (with 95 percent confidence interval from 80% to 87%) for dust deposited on the carpet and 79% (with 95 percent confidence interval from 74% to 85%) for dust ground into the carpet. Although these recoveries are not statistically different, they suggest that recovery of ground-in dust is lower than dust deposited without grind-in, consistent with common sense.

Although differences in recovery after many vacuuming may not be statistically significant, there are statistically significant differences in the measured recovery for the first vacuuming as a function of the dust loading (i.e., weight of dust applied). These recovery measurements are shown in Table A-3. In general, larger loadings were correlated with higher recoveries on the first vacuuming.

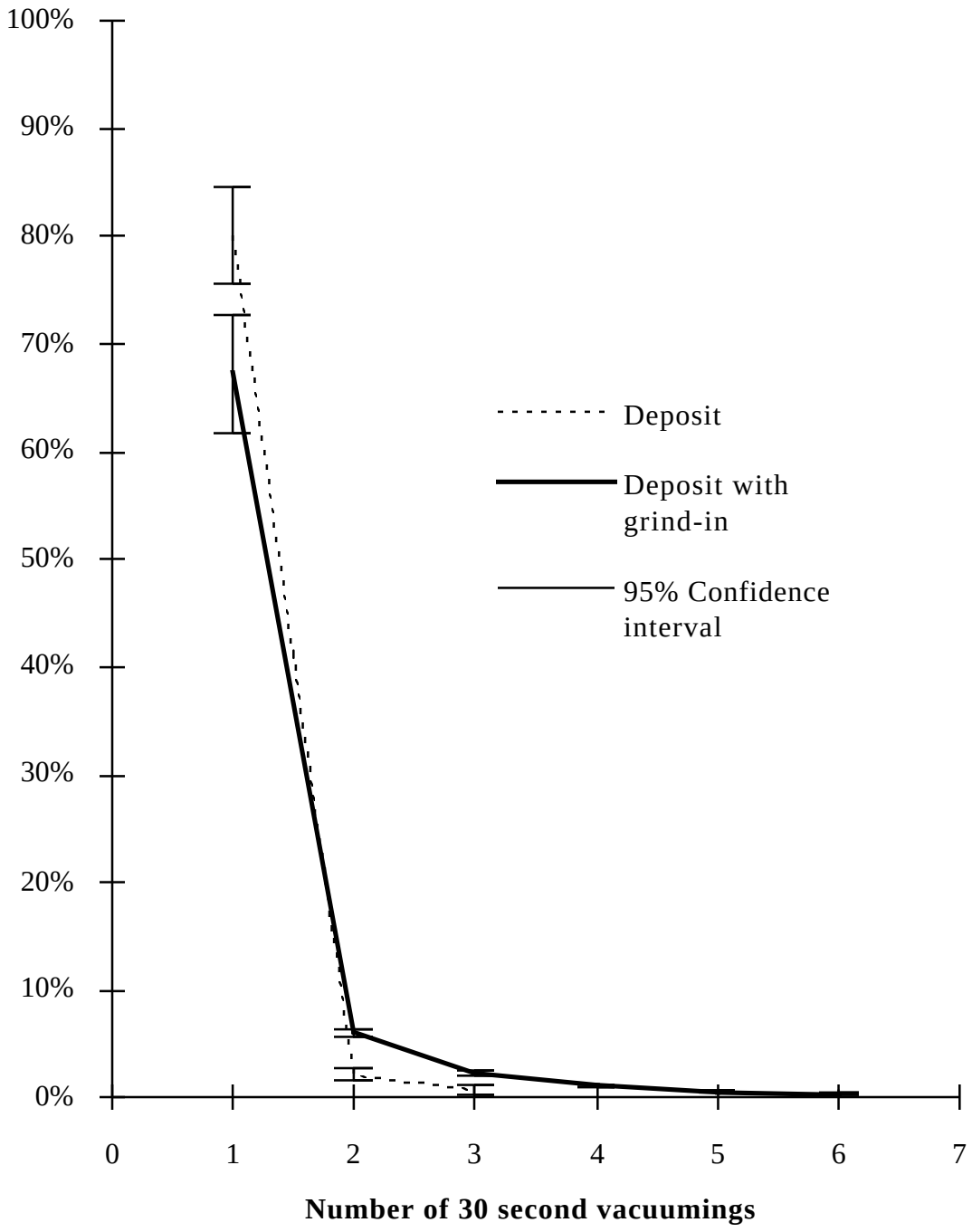


Figure A-9 Dust recovery versus vacuuming effort for dust deposited on the carpet and dust deposited and ground into the carpet

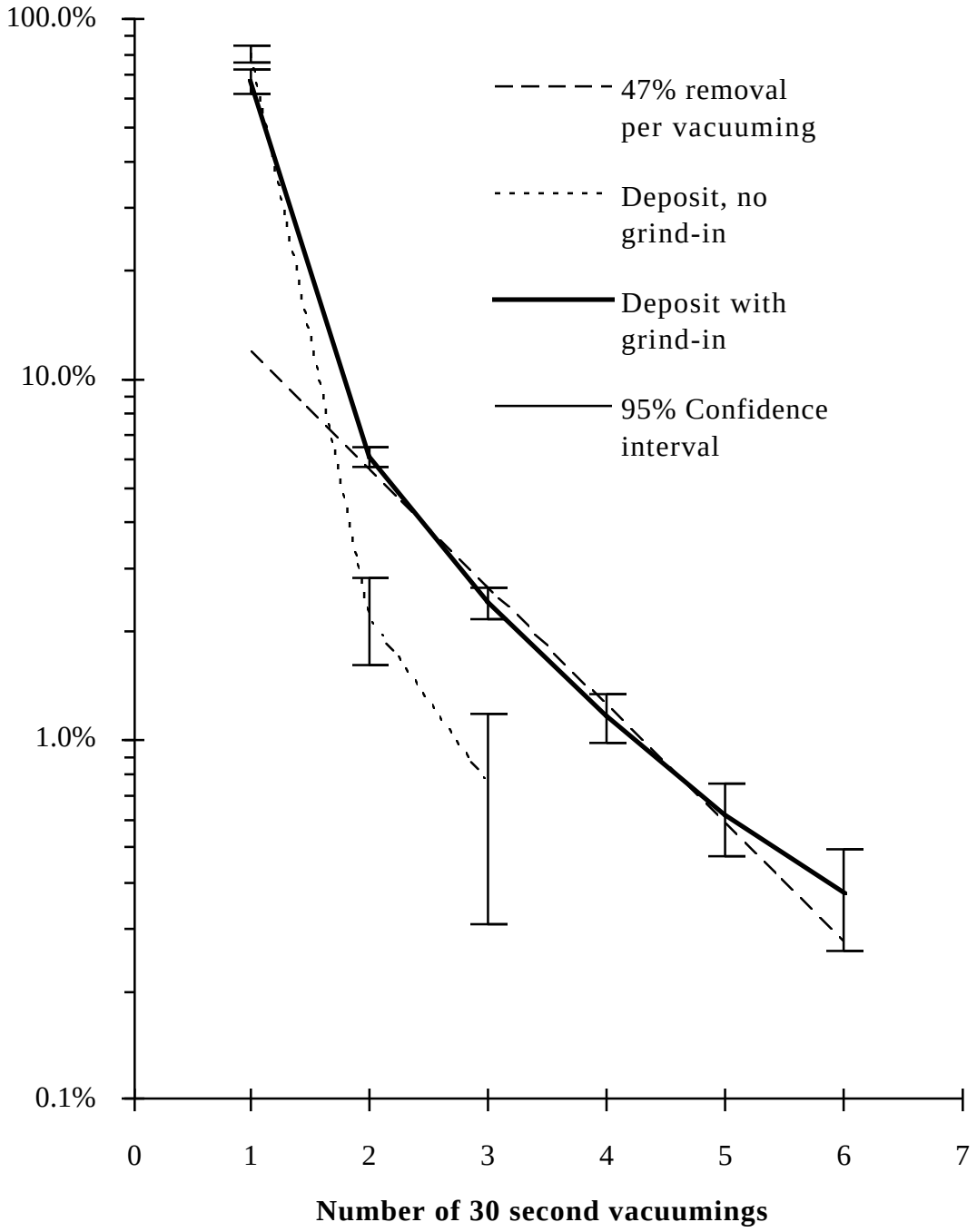


Figure A-10 Dust recovery versus vacuuming effort for dust deposited with and without grind-in compared to fixed removal per vacuuming

Table A-3 Dust recovery on the first vacuuming as a function of the dust loading

Nominal dust loading	Dust deposited only	Dust deposited and ground in
100 mg/sq.ft.	80.1%	67.3%
400 mg/sq.ft.	82.5%	66.7%
1,000 mg/sq.ft.		63.7%
4,000 mg/sq.ft.		72.6%

The weight of dust recovered from the vacuum bags is shown in Figure A-11, along with the regression line relating the dust deposited to the dust collected from the bag. Assuming that the detection limit for lead is 0.8 micrograms, the lead concentration in the dust is 20 μg/ g, and the desired level in the sample is three times the detection limit, then a dust sample with at least 0.120 grams of dust is required. Using the regression relationship, a deposit of at least 1.25 grams of dust is required to obtain 0.120 grams for the vacuum cleaner bag. This target weight of dust is also shown in Figure A-11.

The results of the analysis of Task 3 and 4 suggested that the carryover from test to test is small, that two or three vacuumings will remove virtually all of the dust which might be removed by vacuuming, and thus that using the same carpet sample for successive tests was reasonable. The results also showed that roughly three applications of dust would both shorten the test compared to the original design and provide enough dust to measure the lead in the dust.

A4.5 Analysis of Task 5

In the exhaust emissions tests, Task 5, the dust concentration in the exhaust of the vacuum cleaner was measured before, during, and after a known amount of dust was picked up by the vacuum cleaner. The exhaust dust concentrations were recorded as indicated by the output on the front of the instrument, at one-minute intervals. The weight of dust captured in the vacuum bag was also measured. The dust concentrations were converted to dust amounts to calculate the proportion of the dust picked up by the vacuum which was in the exhaust.

To calculate the exhaust emissions from the vacuum cleaners, information including the gas flow rate (in cubic feet per minute), the amount of dust applied to the turntable (in grams), the exhaust emissions concentration (in mg per cubic meter, recorded both on a strip chart and at one-minute intervals), and the initial and final vacuum cleaner bag weights (in grams) are taken from the data forms for vacuum cleaner emission tests. The strip chart and one-minute interval concentration values are used to obtain exhaust emission estimates. The two methods, the integration method using the strip chart, and trapezoid method using the one-minute readings, produce somewhat different results. The conditions under which one estimate is better than the other are discussed later.

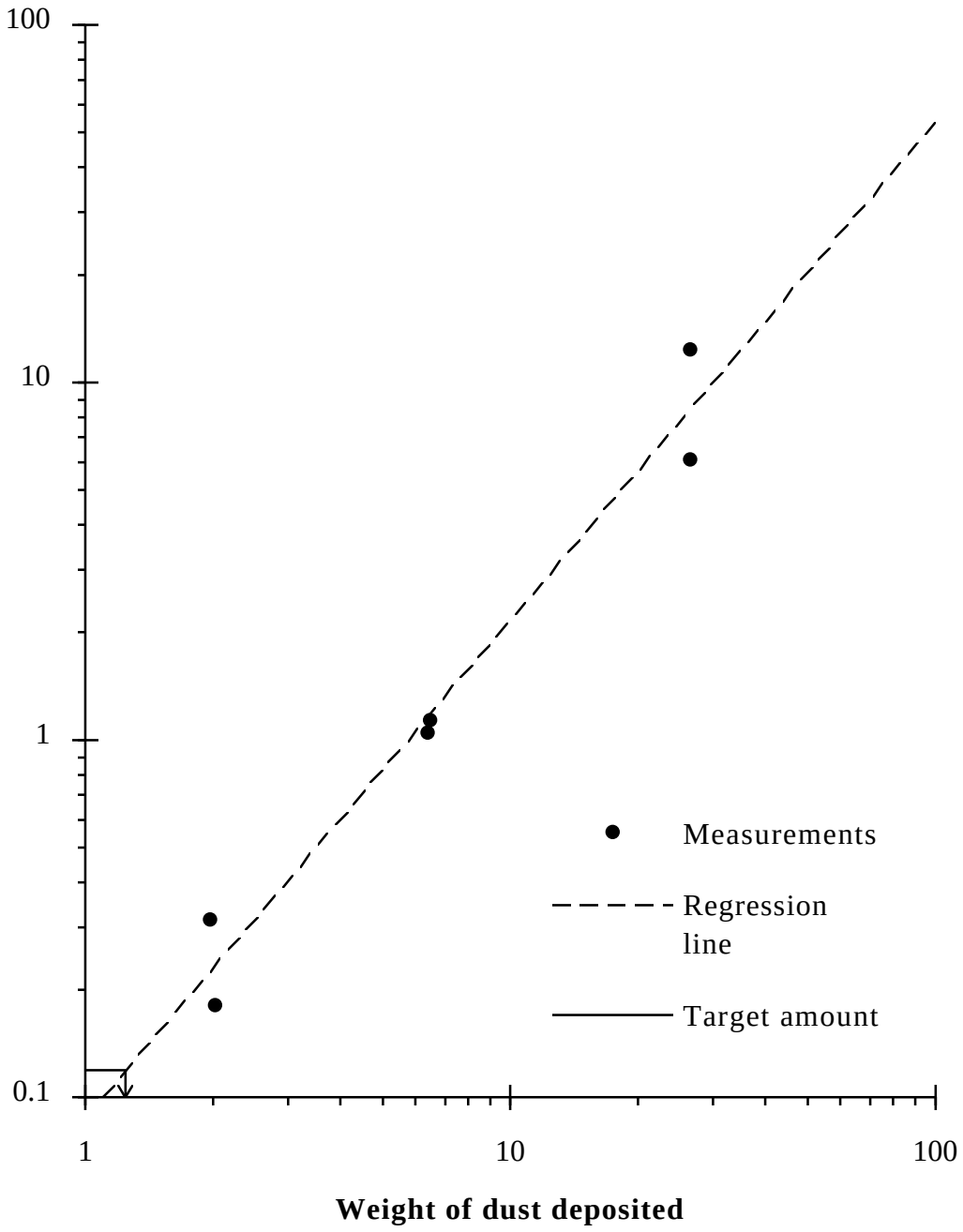


Figure A-11 Weight of dust recovered from the vacuum cleaner bag as a function of the weight of the dust deposited

In the original plan for the pilot tests, the purpose of Task 5 was to evaluate the possibility of measuring the lead content in the dust exhausted from the vacuum cleaners. Preliminary measurements indicated that the exhaust levels were so low that it would not be possible to sample enough dust to measure lead concentrations. Therefore, dust measurements were not attempted. According to the original plan, the purpose of the pilot exhaust tests was to evaluate the feasibility of taking the exhaust measurements. At the time the tests were performed, it was convenient to test all vacuums and, in effect, complete the tests planned for the full study. It had been planned that dust passing through the 250 micron sieved would be used for the pilot tests and that dust passing through the 53 micron sieve would be used for the exhaust tests in the full study. By using dust which passed through the 53 micron sieve for the pilot exhaust tests, it was not necessary to repeat the exhaust tests in the full study.

The following information was used to calculate the exhaust emissions from the vacuum cleaners: (1) the gas flow rate (in cubic feet per minute), (2) the amount of dust applied to the turntable (in grams), (3) the exhaust emissions concentration (in mg per cubic meter), recorded both on a strip chart and at one-minute intervals, and (4) the initial and final vacuum cleaner bag weights (in grams) taken from the data forms for vacuum cleaner emission tests. Two procedures were used to determine the total amount of dust exhausted during the period before, during, and after the dust pickup period: (1) integrating the exhaust dust concentrations recorded each minute using approximating trapezoids and (2) integrating the continuous trace on the strip chart recorder (integration method). The first method was more accurate for the point in time when the emissions were recorded. The second allowed estimation in periods where the emissions were fluctuating and the instantaneous emission level was not representative of the average emissions level.

The integration method approximates the area under the strip chart curve by totaling the number of squares under the curve. For each vacuum cleaner and replicate, an area, in mg, associated with a small square on the strip chart is calculated and multiplied by the number of small squares to estimate the exhaust emissions. For example, vacuum cleaner A-replicate 1 had a flow rate of 75.03 cubic feet per minute, or 2.1246 cubic meters per minute. The area (in mg) of one small square, 0.05 minutes wide and 0.02 mg per cubic meter high, is then calculated as

$$0.02 \text{ mg/m}^3 * 2.1246 \text{ m}^3\text{/min.} * 0.05 \text{ min.} = 0.00212 \text{ mg}$$

For the first time interval, from 0 to 1 minutes, the area under the strip chart curve consisted of 90 small squares. Therefore, the estimate of exhaust emissions for the first time interval is 90 * 0.00212 mg = 0.191 mg. This method works better than the trapezoid method for intervals covering larger areas and whose strip chart curves cannot be accurately estimated with a straight line.

The trapezoid method assumes that the strip chart curve between time intervals can be accurately estimated with a straight line. The area under the curve between two intervals, an estimate of exhaust emissions in that interval, can be calculated using the

trapezoid rule where the concentrations at each interval are the heights of the trapezoids. For example, vacuum cleaner B replicate 1 had concentrations at the second and third minutes of 0.037 and 0.034 mg per cubic meter, respectively. The area of the resulting trapezoid is 0.0355 mg minutes per cubic meter. The area, 0.0355 mg minutes per cubic meter, multiplied by the gas flow rate, 2.269 cubic meters per minute, equals 0.081 mg, the estimate of the exhaust emissions in the first replication of vacuum cleaner B. This method works better than the integration method for intervals covering smaller areas and whose strip chart curves can be accurately estimated by a straight line.

For each of the 13 tests (four tests for vacuum A and three tests each for vacuums B, C, and D), the strip charts were divided into seven intervals (0-1 minutes, 1-2 minutes,..., 6-7 minutes) where the appropriate method for each interval and test was used to estimate the exhaust emissions for that test in that interval. No one-minute intervals were recorded for the first replication of vacuum cleaner A, though, so estimates from the integration method were used. In addition, when borderline cases arose, the exhaust emission estimates from the two methods were similar. Thus, the potential errors resulting from choosing the inappropriate method would be negligible.

Three questions are presented in the work plan for Task 5: How much do the exhaust emissions change when dust is injected into each vacuum cleaner? The exhaust emissions and dust not captured in the vacuum cleaner bags are what percentage of total dust applied to the turntable for each vacuum cleaner? Where are the peaks in the concentrations of exhaust emissions for the vacuum cleaners?

One speculation prior to the tests was that the exhaust emissions would peak early in the test and subsequently decrease as the pores of the vacuum bag were plugged by fine dust particles. The fluctuations in the emissions over time make testing of this hypothesis difficult. When examining the strip charts, the larger exhaust dust concentrations appeared in the beginning and then slowly tapered off, although there were some unexplained late peaks for vacuum cleaner A. Although this general trend could possibly be due to the fact that the larger dust particles were clogging the bag, the late peaks are difficult to interpret. The emissions levels fluctuated too much to make reasonable estimates of the rate at which the emissions decreased after the peak. In general, evidence suggests that concentrations peak in the first minute and decrease to near pre-injection levels during the last minute the turntable is on. However, since the exhaust emissions were close to ambient levels, the concentration peaks are not likely to raise much concern.

The changes in the exhaust emissions resulting from injection of dust into the vacuum cleaner differ significantly from vacuum cleaner to vacuum cleaner. For example, the exhaust emissions from vacuum cleaners A and B while injecting dust were slightly higher than exhaust emissions without injecting the dust. The amount of exhaust emissions expelled from vacuum cleaner C was reduced by 25% while injecting dust into the vacuum cleaner. That is, it reduced dust levels in ambient air, probably because it was equipped with a HEPA filter. Vacuum cleaner D, the upright vacuum,

had the largest average increase in exhaust emissions. Exhaust emissions while injecting dust were six times larger than those when the dust was not being injected. These average exhaust emission levels are shown in Figure A-12 and Table A-4. The minute-by-minute averages are shown in Section A6.5.

There are two possible ways to compute the amount of exhaust emissions. The first and most straightforward is to measure the concentrations of dust in the exhaust as measured by the dust emissions monitor. The second is to calculate the amount of dust not captured in the bag. On average, 4% of the dust placed on the turntable was not captured in the vacuum cleaner bag, with the percentages ranging from over 6% for vacuum cleaner D to 3% for vacuum cleaners A, B, and C[5] However, only about 0.01% of the dust placed on the turntable was expelled as exhaust emissions, with the percentages ranging from 0.021% for vacuum cleaner D to less than 0.001% for vacuum cleaner C. Across all vacuum cleaners, roughly 4% of the dust, that which was not caught in the bag and not measured in the exhaust, has not been accounted for. The missing dust may have adhered to the hose, the outside of the bag but inside the vacuum cleaner (e.g., inside the machinery), or to the turntable.

[5]Test D-3 is considered an outlier and is not used in these calculations

Table A-4 Average exhaust concentrations for each vacuum cleaner exhaust test

Vacuum cleaner	Bag	Ambient air levels	Dust expelled (mg/m^3) as exhaust before, during and after injection			Dust as a percent of dust place on turntable	
			Before	During	After	Dust not captured in the bag	Dust from exhaust emissions
A	1		0.090	0.092	0.065	5.0%	0.020%
A	2		0.057	0.061	0.041	2.4%	0.013%
A	3		0.053	0.037	0.033	2.4%	0.008%
A	4		0.060	0.070	0.051	3.7%	0.015%
B	1	0.004	0.018	0.028	0.015	4.0%	0.006%
B	2	0.009	0.011	0.018	0.011	2.8%	0.004%
B	3	0.006	0.009	0.014	0.010	2.4%	0.003%
C	1	0.004	0.004	0.003	0.003	4.7%	0.001%
C	2	0.013	0.006	0.003	0.003	2.7%	0.001%
C	3	0.012	0.004	0.003	0.003	2.4%	0.001%
D	1	0.012	0.031	0.158	0.020	7.6%	0.021%
D	2	0.017	0.019	0.091	0.015	4.9%	0.011%
D	3	0.012	0.013	0.093	0.013	84.0%	0.012%
Average for each vacuum cleaner							
A			0.065	0.065	0.048	3.4%	0.014%
B		0.006	0.013	0.020	0.012	3.0%	0.005%
C		0.010	0.005	0.003	0.003	3.3%	0.001%
D		0.014	0.021	0.114	0.016	6.3% *	0.015%

*Average excluding the outlier of 84%

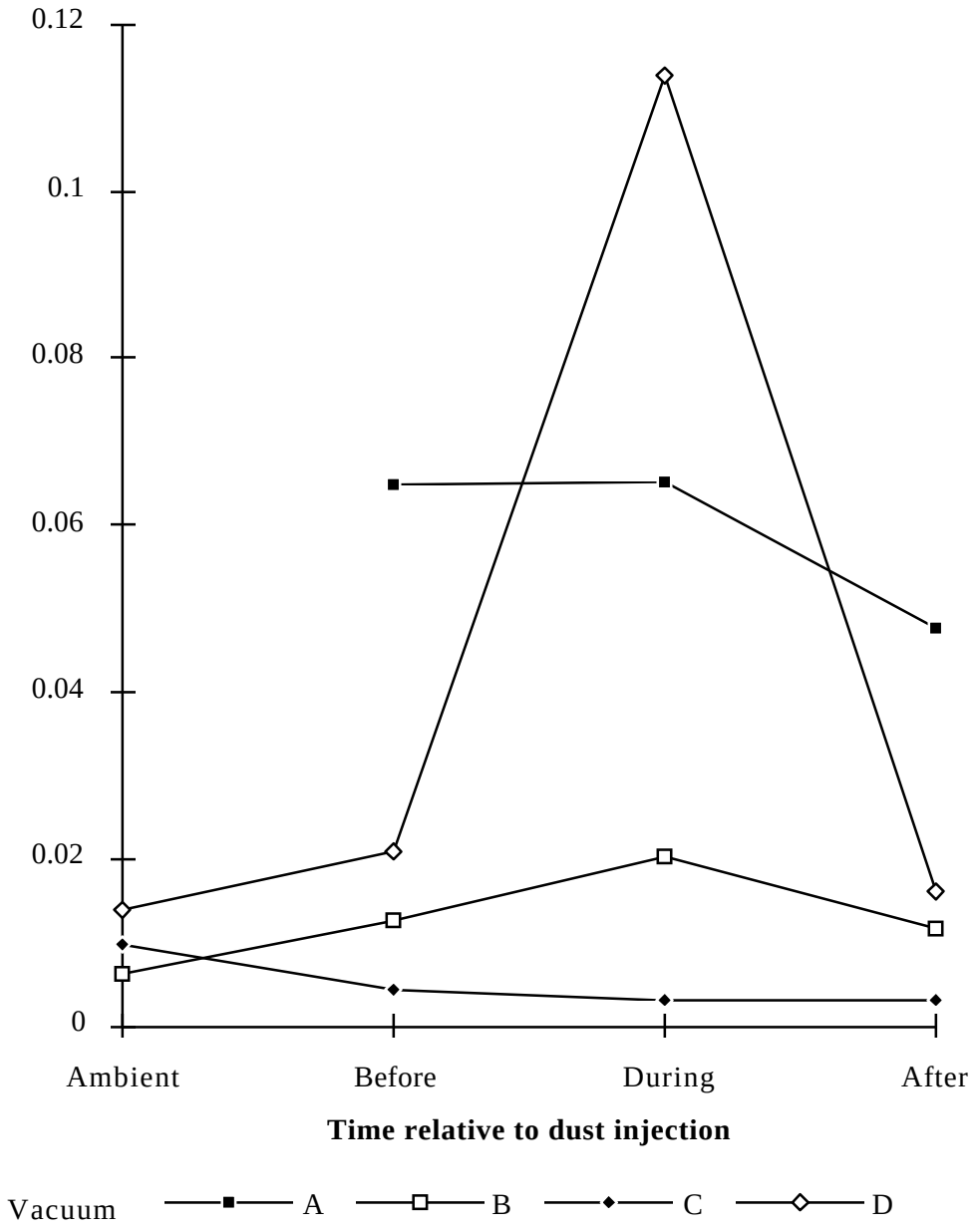


Figure A-12 Average dust emissions before, during, and after injection of dust

A5.0 DISCUSSION OF RESULTS

The results of the separate tasks which made up the pilot tests are summarized below, along with associated changes for the tests in the full study.

Task 1

Task 1 showed that there appears to be a trend in the vacuum cleaner bag weights consistent with the assumption that they are adjusting to the laboratory environment. Although there is evidence for a relative humidity effect, and possibly a temperature effect, on the weight measurements, these effects were small compared to the trend over time and were difficult to estimate because the temperature and relative humidity stayed relatively constant during the tests.

The trend suggests that the time between stopping the vacuuming and weighing the bag must be carefully controlled to minimize the measurement variance associated with weighing an object whose weight is changing. An analysis of the data suggests that adequate precision can be obtained by waiting three minutes between turning off the vacuum and weighing the vacuum bag; little added precision is obtained by waiting longer. Based on a preliminary analysis, the time between vacuuming and weighing was set at five minutes for Tasks 3, 4, and 5. Following the more complete analysis described here, and considering the time involved and flow of work in the lab, MRI and Westat decided to set the time between vacuuming and weighing the vacuum bag at three minutes in the full study.

The precision of the recovery measurements was better than originally anticipated during the preparation of the QAPjP. Therefore, the study as originally designed could easily achieve the data quality objectives. Due to subsequent budget considerations, the number of tests planned for the full study was reduced. With the reduced number of tests, it was anticipated that the original data quality objectives would be achieved based on the precision attained in the pilot tests.

Task 2

In Task 2, the platform for holding the carpet samples performed well. The design was not modified for the full study.

Task 3

The primary purpose of Task 3 was to assess the significance of carryover of dust from one test to the next and to evaluate whether or not new carpet samples are needed for each test.

In the first part of the task it was determined that the carpet could be vacuumed such that few fibers would be picked up in each 40-second vacuuming and this might affect

the recovery estimate. At the same time, it was determined that the time to precondition each carpet was roughly a half hour.

The tests designed to identify significant carryover from test to test showed no measurable carryover. Without carryover, recovery measurements can be made using the same carpet sample for all, or many, tests. Use of the one carpet sample for multiple tests also reduces the time required for each carpet test.

Task 4

The purpose of Task 4 was to determine how much dust was required. The tests were set up also to determine if depositing all the dust at once gave results similar to depositing the dust in multiple applications.

The analysis of the Task 4 data included the Task 3 data and allowed for estimation of recovery as a function of vacuuming effort. The results of a regression analysis indicated that the recovery on carpets was roughly 80% and that recovery was lower when the dust was ground in than when the dust was simply deposited on the carpet. Although there was some evidence of carryover, it was small after the third 30-second vacuuming. The dust removed from the vacuum bag for lead analysis, when using three applications of dust at the low loading amount, was adequate for the lead analysis.

Based on results from Task 4, for the full study it was decided to apply the dust in three applications followed by three vacuumings without applying dust.

Task 5

The results of Task 5 indicated that the exhaust emissions from the vacuum cleaners were low and that very little of the dust passed through the vacuum cleaner bags. Because the tests specified for the full study were completed during the pilot test, the exhaust tests will not be performed during the full study.

Other test procedure revisions

Due to continuing concern over the possibility that carpet fibers might affect the measurements, particularly early in the study, that dust accumulated in the carpet might affect later measurements, and that carryover might have some effect on the results, it was decided to vacuum the carpet for each test prior to depositing the dust. This initial vacuuming provides a measure of the dust or fibers which might bias the recovery estimate. The results from this initial vacuuming will be used to correct for any bias or carryover and make the statistical analysis simpler.

The decision to use the same carpet sample for many tests was further modified such that for all substrates, four substrate samples were prepared. Each sample in the full study is to be used for tests with one combination of dust loading and dust lead

concentration. In effect, each substrate sample corresponds to a house with either low or high dust lead concentrations and low and high dust loadings prior to vacuuming. The use of the same substrate for all tests, with the associated dust lead concentration and loading, corresponds roughly to the history of vacuuming in a home where there is a sequence of dust depositions and vacuumings over time.

A6.0 LABORATORY DATA

A6.1 TASK 1: Determine the stability of tare weights for new, clean vacuum cleaner bags

Tables A-5, A-6, A-7 and A-8 consist of the data generated from Task 1. The description of the data in each column of Table A-5 and A-6 is listed below:

Column Name	Description
Time	Number of minutes since the initial weighing
Bag A Weight	Weight of the bag for vacuum cleaner A
Bag B Weight	Weight of the bag for vacuum cleaner B
Bag C Weight	Weight of the bag for vacuum cleaner C
Bag D Weight	Weight of the bag for vacuum cleaner D
Cassette 1 Weight	Weight of the first cassette used in the task
Cassette 2 Weight	Weight of the second cassette used in the task

The description of the data in each column of Table A-7 and A-8 is listed below:

Date	Date of the test
Time	Time the test was performed
Relative Humidity	Relative humidity at the beginning of the test
Temperature	Temperature at the beginning of the test
Wt of Housevac A Bag	Weight of the bag for vacuum cleaner A
Wt of Housevac B Bag	Weight of the bag for vacuum cleaner B
Wt of Housevac C Bag	Weight of the bag for vacuum cleaner C
Wt of Housevac D Bag	Weight of the bag for vacuum cleaner D
Form No	Form number - 1 signifies the vacuum cleaner bags were weighed without running the vacuum cleaners and 2 signifies the vacuum cleaner bags were weighed after running the vacuum cleaners for 1 minute
Bag	Sequential number to distinguish between bags
Replication	Replication of test on the same cassette

The procedure generating the data in table A-5 follows:

1) Run vacuum cleaner 40 sec with new bag
2) Repeat above 3 times with 1 minute between using same bag
3) Run vacuum cleaner for 40 sec
4) Immediately weigh bag, and record wt every minute for 10 min

5) Repeat steps 1) to 4) once
6) Repeat steps 1) to 5) for each vacuum cleaner

The procedure generating the data in table A-6 follows:

1) Obtain cassette that has been acclimated to room for more than 24 hours
2) Weigh cassette - record wt every minute for 5 min
3) Remove top half of cassette; install blue nozzle sampler
4) Run sampler for 120 sec
5) Remove cassette; reinstall top half
6) Weigh cassette; record wt every minute for 5 min
7) Repeat items 3) to 6) one time
8) Repeat 1) to 7) with another cassette, once

The procedure generating the data in table A-7 follows:

1) Weigh each bag type 10 times, one half hour between

The procedure generating the data in table A-8

1) Insert bag
2) Run vacuum cleaner 5 min; discard bag
3) Weigh new bag and insert in vacuum cleaner
4) Run vacuum cleaner for 1 min, reweigh bag
5) Repeat run/weigh 10 times with same bag

Table A-5: Tare weight of vacuum cleaner bags at one minute intervals for Task 1

Gravimetric Data					
Time (min)	Bag A Weight (g)	Bag B Weight (g)	Bag C Weight (g)	Bag D Weight (g)	Bag
0	37.547	36.121	30.309	35.161	1
1	37.544	36.118	30.303	35.194	1
2	37.544	36.112	30.303	35.221	1
3	37.542	36.107	30.302	35.238	1
4	37.542	36.103	30.300	35.255	1
5	37.541	36.100	30.301	35.269	1
6	37.541	36.099	30.301	35.281	1
7	37.541	36.098	30.301	35.290	1
8	37.539	36.098	30.302	35.299	1
9	37.540	36.092	30.300	35.308	1
10	37.539	36.092	30.300	35.313	1
0	36.755	40.938	30.221	34.455	2
1	36.754	40.933	30.218	34.467	2
2	36.752	40.929	30.219	34.483	2
3	36.752	40.925	30.221	34.505	2
4	36.752	40.923	30.221	34.511	2
5	36.752	40.920	30.222	34.518	2
6	36.752	40.919	30.224	34.527	2
7	36.752	40.918	30.226	34.536	2
8	36.752	40.916	30.226	34.542	2
9	36.751	40.914	30.227	34.548	2
10	36.750	40.913	30.228	34.553	2

Table A-6: Tare weight of sampling cassette at one minute intervals for Task 1

Gravimetric Data			
Time (min)	Replication	Cassette 1 Weight (g)	2 Weight (g)
0	1	19.4825	19.3281
1	1	19.4822	19.3260
2	1	19.4821	19.3253
3	1	19.4820	19.3248
4	1	19.4820	19.3245
5	1	19.4820	19.3242
0	2	19.4852	19.3222
1	2	19.4841	19.3210
2	2	19.4837	19.3205
3	2	19.4837	19.3201
4	2	19.4831	19.3198
5	2	19.4829	19.3195
0	3	19.4840	19.3211
1	3	19.4829	19.3200
2	3	19.4823	19.3194
3	3	19.4820	19.3191
4	3	19.4817	19.3189
5	3	19.4814	19.3186

Table A-7: Tare weighht of vacuum cleaner bags at 30 minute interrvals for Task 1

Gravimetric Data							
Date	Time	Relative Humidity (%)	Temperature (F)	Weight of Housevac A Bag (g)	Weight of Housevac B Bag (g)	Weight of Housevac C Bag (g)	Weight of Housevac D Bag (g)
6/24/93	11:00	47.0	69.8	35.275	41.010	30.462	41.390
6/24/93	11:30	47.6	70.2	35.288	41.024	30.467	41.406
6/24/93	12:00	47.6	70.3	35.298	41.042	30.472	41.411
6/24/93	12:30	47.6	70.4	35.292	41.046	30.470	41.410
6/24/93	13:00	48.5	70.7	35.301	41.053	30.481	41.418
6/24/93	13:30	47.9	70.6	35.296	41.050	30.477	41.416
6/24/93	14:00	47.7	71.0	35.291	41.042	30.477	41.414
6/24/93	14:30	48.2	71.2	35.296	41.040	30.479	41.417
6/24/93	15:00	48.3	70.9	35.296	41.037	30.480	41.413
6/24/93	15:30	46.6	70.8	35.294	41.024	30.472	41.403

Table A-8: Tare weight of vacuum cleaner bags after one minute of use, for Task 1

Gravimetric Data					
Date	Time	(%)	(F)	Weight of Housevac Bag (g)	Housevac
6/25/93	13:32	40.2	70.8	36.005	A
6/25/93	13:44	39.9	71.0	35.972	A
6/25/93	13:59	39.8	71.0	35.952	A
6/25/93	14:11	39.6	71.2	35.926	A
6/25/93	14:28	39.7	71.1	35.915	A
6/25/93	14:43	39.5	71.3	35.913	A
6/25/93	14:56	39.4	71.4	35.905	A
6/25/93	15:10	39.2	71.6	35.900	A
6/25/93	15:28	39.3	71.6	35.902	A
6/25/93	15:43	39.4	71.6	35.891	A
6/25/93	15:57	39.4	71.6	35.892	A
6/25/93	13:35	40.2	70.8	41.656	B
6/25/93	13:47	40.0	71.1	41.617	B
6/25/93	14:01	39.7	71.2	41.599	B
6/25/93	14:14	39.6	71.1	41.588	B
6/25/93	14:31	39.6	71.2	41.575	B
6/25/93	14:45	39.6	71.2	41.570	B
6/25/93	14:58	39.5	71.3	41.564	B
6/25/93	15:12	39.3	71.5	41.562	B
6/25/93	15:30	39.2	71.6	41.563	B
6/25/93	15:45	39.5	71.5	41.552	B
6/25/93	15:59	39.3	71.6	41.550	B
6/25/93	13:37	40.2	70.8	30.250	C
6/25/93	13:49	39.9	71.1	30.246	C
6/25/93	14:03	39.8	71.1	30.241	C
6/25/93	14:17	39.8	71.1	30.234	C
6/25/93	14:33	39.5	71.2	30.238	C
6/25/93	14:47	39.6	71.2	30.238	C
6/25/93	15:00	39.5	71.3	30.235	C
6/25/93	15:14	39.4	71.5	30.237	C
6/25/93	15:32	39.4	71.5	30.237	C
6/25/93	15:47	39.6	71.5	30.237	C
6/25/93	16:02	39.3	71.5	30.235	C
6/25/93	13:39	40.3	70.8	34.710	D
6/25/93	13:51	39.8	71.1	34.530	D
6/25/93	14:05	39.7	71.1	34.465	D
6/25/93	14:21	39.8	71.0	34.443	D
6/25/93	14:35	39.6	71.1	34.414	D
6/25/93	14:49	39.7	71.2	34.394	D
6/25/93	15:03	39.4	71.3	34.376	D
6/25/93	15:16	39.4	71.4	34.371	D
6/25/93	15:36	39.4	71.4	34.358	D
6/25/93	15:50	39.5	71.4	34.345	D
6/25/93	16:05	39.3	71.5	34.340	D

A6.2 TASK 2: Demonstrate method of securing carpet and upholstery substrates for testing vacuum cleaners

A 6-in high rectangular table(1.83 m x 0.69 m) with the top of the table made from 3/ 4-in thick exterior grade plywood (per ASTM Method F608-89) was constructed. A mechanism was provided for securing carpet section s at the corners of the table and for securing upholstery sections along the entire length at both ends. A pad was placed underneath the carpet sections, and a 1/ 2-in thick foam pad was placed underneath the upholstery sections.

The suitability of the table for vacuum cleaner tests was determined by vacuuming a carpet section with the upright vacuum (vacuum cleaner D) and with one of the canister vacuum cleaners with beater bar. Similarly, an upholstery section was vacuumed with the same two vacuum cleaners using the proper upholstery attachment.

The table was tried out on June 30, 1993. The method of securing substrates to the table worked well for carpet sections, However, upholstery sections had to be clamped along one end and then stretched tight before clamping onto the table at the opposite end. Not doing so allowed the upholstery section to ripple up in front of the vacuum cleaner nozzle. Two pieces of channel were cut for proper securing of upholstery.

A6.3 TASK 3: Determine if preconditioning procedures are feasible for using new carpet in the laboratory tests, and determine if the use of the same substrate for each series of tests is feasible

Tables A-9 and A-10 consist of the data generated from Task 3. The description of the data in each column of Table A-9 is listed below:

Column Name	Description
Time	Time the test was performed
Bag Wt	Weight of the vacuum cleaner bag
RH	Relative humidity at the time the bag weight was observed
Temp	Temperature at the time the bag weight was observed

The description of the data in each column of Table A-10 is listed below:

Vac Run	Order of the vacuuming
Increase	Increase in the bag weight from the vacuuming
RH	Relative humidity at the time the bag weight was observed
Temp	Temperature at the time the bag weight was observed
Bag No	Sequential number to distinguish between the bags
Measurement Type	Type of dust retrieval used - 1 signifies the wand was vacuumed after every ninth test, 2 signifies the wand was vacuumed after every third test, and 3 signifies the wand was vacuumed as a part of each test
Dust Amount	Dust amount deposited - 1 signifies 100 mg/ sq ft and 2 signifies 400 mg/sq ft
Dust Despot	Amount of dust deposited on the substrate
Dust from Wand	Amount of dust vacuumed from the wand (except for measurement type 3)
Time	Time the test was performed

The procedure for generating the data in table A-9

1) Vac entire carpet 5 min; discard bag
2) Weigh new bag, vac for 5 min
3) Reweigh same bag; vac 5 min
4) Repeat reweigh/vac 10 times

The procedures for generating the data in table A-10

1) Vacuum wand and brush; discard bag

2) Insert new tared bag
3) Apply dust; vac for 30 sec, wait 5 min, reweigh bag
4) Vac for 30 sec, wait 5 min, reweigh bag
5) Vac for 30 sec, wait 5 min, reweigh bag
6) Repeat items 2) through 5) above
7) Repeat items 2) through 5) again
8) Vacuum off wand and brush
9) Reweigh Bag

Table A-9: Fiber conditioning, Task 3

Gravimetric Data			
Time	Bag Wt (g)	RH (%)	Temp (F)
15:55	35.572	52.6	73.5
16:06	36.237	52.4	73.6
16:19	36.705	52.2	73.6
16:32	36.900	52.0	73.7
16:44	37.038	51.6	73.7
16:56	37.202	51.6	73.8
17:10	37.215	51.1	73.8
17:21	37.231	50.9	73.8
17:32	37.247	50.9	73.8
17:43	37.262	50.8	74.0
17:54	37.285	50.7	74.1
18:01	37.316	50.3	74.1
18:11	37.350	50.2	73.8
18:22	37.372	50.0	73.5
18:35	37.384	49.8	73.4
33:01	37.433	43.9	71.4

Table A-10: Dust carry-over test for Task 3

Gravimetrics Data									
Vac Run	Increase (g)	RH (%)	Temp (F)	Bag No	Measurement Type	Dust Amount	Dust Deposit (g)	Dust from Wand (g)	Time
1st vac	0.619	44.7	74.4	1	1	1	0.726	0	14:20
2nd vac	0.011	44.5	74.3	1	1	1	0.000	0	14:25
3rd vac	0.006	44.5	74.2	1	1	1	0.000	0	14:30
1st vac	0.383	44.4	74.2	2	1	1	0.685	0	14:59
2nd vac	0.018	44.4	74.3	2	1	1	0.000	0	15:04
3rd vac	0.021	44.8	74.3	2	1	1	0.000	0	15:08
1st vac	0.571	44.4	74.4	3	1	1	0.682	0	15:28
2nd vac	0.024	44.5	74.5	3	1	1	0.000	0	15:36
3rd vac	0.003	44.3	74.4	3	1	1	0.000	0.02	15:44
1st vac	2.270	44.3	72.3	4	1	2	2.687	0	11:02
2nd vac	0.061	44.2	72.3	4	1	2	0.000	0	11:08
3rd vac	0.012	44.0	72.4	4	1	2	0.000	0	11:15
1st vac	2.252	43.7	72.5	5	1	2	2.724	0	11:30
2nd vac	0.033	43.6	72.6	5	1	2	0.000	0	11:36
3rd vac	0.007	43.4	72.6	5	1	2	0.000	0	11:43
1st vac	2.021	43.4	72.8	6	1	2	2.618	0	11:57
2nd vac	0.046	43.1	72.8	6	1	2	0.000	0	12:04
3rd vac	0.008	42.9	72.8	6	1	2	0.000	0.04	12:11
1st vac	0.592	42.5	73.2	7	2	1	0.677	0	14:48
2nd vac	0.020	42.4	73.2	7	2	1	0.000	0	14:54
3rd vac	0.002	42.6	73.3	7	2	1	0.000	0.004	15:00
1st vac	0.533	42.3	73.5	8	2	1	0.661	0	15:28
2nd vac	0.022	42.4	73.4	8	2	1	0.000	0	15:34
3rd vac	0.000	42.2	73.5	8	2	1	0.000	0.017	15:41
1st vac	0.532	42.0	73.6	9	2	1	0.671	0	16:06
2nd vac	0.016	42.3	73.6	9	2	1	0.000	0	16:13
3rd vac	0.007	42.0	73.6	9	2	1	0.000	0.017	16:20
1st vac	2.257	52.4	73.9	10	2	2	2.675	0	9:37
2nd vac	0.061	52.9	74.1	10	2	2	0.000	0	9:43
3rd vac	0.036	52.5	74.1	10	2	2	0.000	0.018	9:50
1st vac	2.278	52.9	74.5	11	2	2	2.690	0	10:12
2nd vac	0.096	53.0	74.6	11	2	2	0.000	0	10:19
3rd vac	0.019	53.0	74.6	11	2	2	0.000	0.03	10:25
1st vac	2.272	53.2	74.8	12	2	2	2.729	0	10:49
2nd vac	0.084	53.0	74.9	12	2	2	0.000	0	10:56
3rd vac	0.030	53.0	75.0	12	2	2	0.000	0.033	11:03
1st vac	0.548	51.8	75.3	13	3	1	0.657	0	12:59
2nd vac	0.008	51.9	75.3	13	3	1	0.000	0	13:08
3rd vac	0.014	51.3	75.5	13	3	1	0.000	0	13:15
1st vac	0.559	49.9	75.5	14	3	1	0.665	0	13:42
2nd vac	0.017	49.5	75.5	14	3	1	0.000	0	13:51
3rd vac	0.002	48.8	75.6	14	3	1	0.000	0	14:01
1st vac	0.572	49.2	75.8	15	3	1	0.671	0	14:28

Table A-10: Dust carry-over test for Task 3 (continued)

Gravimetrics Data									
Vac Run	Increase (g)	RH (%)	Temp (F)	Bag No	Measurement Type	Dust Amount	Dust Deposit (g)	Dust from Wand (g)	Time
2nd vac	0.004	48.5	75.8	15	3	1	0.000	0	14:36
3rd vac	0.010	48.4	75.9	15	3	1	0.000	0	14:44
1st vac	2.229	48.5	76.1	16	3	2	2.627	0	15:10
2nd vac	0.041	48.4	76.0	16	3	2	0.000	0	15:18
3rd vac	0.029	48.3	75.9	16	3	2	0.000	0	15:26
1st vac	2.295	48.4	76.1	17	3	2	2.706	0	15:51
2nd vac	0.064	48.3	76.2	17	3	2	0.000	0	16:01
3rd vac	0.024	48.5	76.2	17	3	2	0.000	0	16:10
1st vac	2.277	47.6	76.2	18	3	2	2.710	0	16:34
2nd vac	0.097	47.3	76.2	18	3	2	0.000	0	16:42
3rd vac	0.048	47.1	76.2	18	3	2	0.000	0	16:49

A6.4 Determine the amount of dust needed for the tests

Table A-11 consists of the data generated from Task 4. The description of the data in each column of Table A-11 is listed below:

Column Name	Description
Run No	Order of the vacuuming within each series of tests
Date	Date of the test
Time	Time of the test
Diff	Increase in bag weight from the previous vacuuming
RH	Relative humidity at the time the bag weight was observed
Temp	Temperature at the time the bag weight was observed
Bag No	Sequential number to distinguish between vacuum cleaner bags
Meas Type	Procedure used to perform the test - a description of each procedure is at the bottom of the page
Dust Amount	Dust amount deposited - 1 signifies 100 mg/ sq ft and 2 signifies 400 mg/sq ft
Amount Deposit	Amount of dust deposited on the substrate and not groundin to the substrate
Amount Ground-in	Amount of dust ground-in to the substrate
Amount Picked by Wand	Amount of dust vacuumed from the wand (except for measurement type 3)

The procedure for generating the data in Table A-11 with a measurement type of 4 follows:

1) Vacuum carpet 3 times, discard bag
2) Warm up vacuum cleaner for 30 seconds
3) Insert new tared bag
4) Apply dust and embed
5) Vacuum 30 sec; wait 5 minutes; reweigh bag
6) Repeat steps 4) and 5), a total of 10 times
7) Recover dust from bag, and weigh dust (not bag)
8) Repeat all above, one time

The procedure for generating the data in Table A-11 with a measurement type of 5 follows:

1) Vacuum carpet 3 times, discard bag
2) Warm up vacuum cleaner for 30 seconds

3) Insert new tared bag
4) Apply dust and embed
5) Vacuum 30 sec; wait 5 minutes; reweigh bag
6) Repeat step 5), a total of 10 times
7) Repeat all above, one time

The procedure for generating the data in Table A-11 with a measurement type of 6 follows:

1) Vacuum carpet 3 times, discard bag
2) Warm up vacuum cleaner for 30 seconds
3) Insert new tared bag
4) Apply dust and embed
5) Vacuum 30 sec; wait 5 minutes; reweigh bag
6) Repeat steps 4) and 5), a total of 3 times
7) Vac and weigh 3 more times
8) Recover dust from bag, and weigh dust (not bag)
9) Repeat all above, one time

Table A-11: Testing different amounts of dust and vacuuming the wand for Task 4

Gravimetrics Data											
Run No	Date	Time	Diff (g)	RH (%)	Temp (F)	Bag No	Meas Type	Dust Amount	Amount Deposit (g)	Amount Ground-in (g)	Amount Picked by Wand (g)
1	7/9/93	9:20	0.480	51.5	75.8	19	4	1	0	0.674	0.000
2	7/9/93	9:32	0.488	51.3	75.8	19	4	1	0	0.643	0.000
3	7/9/93	9:43	0.511	51.2	76.0	19	4	1	0	0.649	0.000
4	7/9/93	9:52	0.539	51.2	76.1	19	4	1	0	0.641	0.000
5	7/9/93	10:01	0.510	51.0	76.1	19	4	1	0	0.653	0.000
6	7/9/93	10:09	0.498	51.5	76.2	19	4	1	0	0.648	0.000
7	7/9/93	10:19	0.509	51.3	76.2	19	4	1	0	0.626	0.000
8	7/9/93	10:31	0.468	51.5	76.3	19	4	1	0	0.663	0.000
9	7/9/93	10:39	0.508	51.2	76.2	19	4	1	0	0.631	0.000
10	7/9/93	10:48	0.503	51.2	76.4	19	4	1	0	0.640	0.000
1	7/9/93	13:01	0.460	51.6	76.8	20	4	1	0	0.631	0.000
2	7/9/93	13:11	0.499	52.1	76.8	20	4	1	0	0.688	0.000
3	7/9/93	13:20	0.493	51.4	76.8	20	4	1	0	0.673	0.000
4	7/9/93	13:29	0.435	50.9	76.7	20	4	1	0	0.615	0.000
5	7/9/93	13:39	0.466	51.3	77.0	20	4	1	0	0.639	0.000
6	7/9/93	13:50	0.466	51.5	77.0	20	4	1	0	0.639	0.000
7	7/9/93	13:59	0.498	50.3	77.1	20	4	1	0	0.646	0.000
8	7/9/93	14:20	0.433	50.5	77.4	20	4	1	0	0.634	0.000
9	7/9/93	14:31	0.498	50.7	77.5	20	4	1	0	0.659	0.000
10	7/9/93	14:40	0.484	50.8	77.7	20	4	1	0	0.631	0.000
1	7/9/93	15:49	1.741	51.2	78.0	21	4	2	0	2.570	0.000
2	7/9/93	15:57	1.862	52.0	78.1	21	4	2	0	2.622	0.000
3	7/9/93	16:05	1.592	51.0	77.9	21	4	2	0	1.835	0.000
4	7/9/93	16:11	2.028	51.1	77.9	21	4	2	0	2.722	0.000
5	7/9/93	16:18	2.060	51.2	77.9	21	4	2	0	2.753	0.000
6	7/9/93	16:25	2.492	51.0	78.0	21	4	2	0	3.482	0.000
7	7/9/93	16:34	2.215	51.2	78.0	21	4	2	0	2.664	0.000
8	7/9/93	16:41	1.988	50.8	78.1	21	4	2	0	2.629	0.000
9	7/9/93	16:48	2.039	51.8	78.1	21	4	2	0	2.504	0.000
10	7/9/93	16:55	2.231	51.9	78.0	21	4	2	0	2.614	0.000
1	7/12/93	10:14	1.838	48.8	75.1	22	4	2	0	2.732	0.000
2	7/12/93	10:24	1.923	49.0	75.2	22	4	2	0	1.861	0.000
3	7/12/93	10:35	1.912	48.9	75.4	22	4	2	0	2.657	0.000
4	7/12/93	11:02	1.974	48.7	75.9	22	4	2	0	2.674	0.000
5	7/12/93	11:11	2.012	48.3	75.9	22	4	2	0	2.594	0.000
6	7/12/93	11:21	2.245	48.9	76.1	22	4	2	0	2.606	0.000
7	7/12/93	11:29	2.319	48.5	76.1	22	4	2	0	2.710	0.000
8	7/12/93	11:40	2.019	48.2	76.2	22	4	2	0	2.671	0.000
9	7/12/93	11:52	2.118	48.2	76.3	22	4	2	0	2.629	0.000
10	7/12/93	12:04	2.023	48.5	76.4	22	4	2	0	2.618	0.000
1	7/12/93	16:05	4.419	51.0	76.9	23	5	3	0	6.662	0.000
2	7/12/93	16:14	0.616	55.0	77.0	23	5	3	0	0.000	0.000
3	7/12/93	16:21	0.232	56.0	77.0	23	5	3	0	0.000	0.000

Table A-11: Data from Task 4 (continued)

Gravimetrics Data											
Run No	Date	Time	Diff (g)	RH (%)	Temp (F)	Bag No	Meas Type	Dust Amount	Amount Deposit (g)	Amount Ground-in (g)	Amount Picked by Wand (g)
4	7/12/93	16:31	0.129	50.8	77.2	23	5	3	0	0.000	0.000
5	7/12/93	16:38	0.091	53.0	77.2	23	5	3	0	0.000	0.000
6	7/12/93	16:44	0.067	50.5	77.2	23	5	3	0	0.000	0.000
7	7/12/93	16:51	0.066	50.7	77.3	23	5	3	0	0.000	0.000
8	7/12/93	16:57	0.050	50.6	77.3	23	5	3	0	0.000	0.000
9	7/12/93	17:03	0.045	50.5	77.4	23	5	3	0	0.000	0.000
10	7/12/93	17:09	0.035	48.8	77.2	23	5	3	0	0.000	0.000
1	7/13/93	9:58	4.465	52.6	76.3	24	5	3	0	6.722	0.000
2	7/13/93	10:05	0.466	52.6	76.5	24	5	3	0	0.000	0.000
3	7/13/93	10:11	0.204	52.6	76.5	24	5	3	0	0.000	0.000
4	7/13/93	10:19	0.123	52.6	76.7	24	5	3	0	0.000	0.000
5	7/13/93	10:25	0.083	52.9	76.6	24	5	3	0	0.000	0.000
6	7/13/93	10:33	0.065	52.9	76.6	24	5	3	0	0.000	0.000
7	7/13/93	10:40	0.047	53.8	76.7	24	5	3	0	0.000	0.000
8	7/13/93	10:46	0.040	53.4	76.7	24	5	3	0	0.000	0.000
9	7/13/93	10:53	0.033	54.0	76.6	24	5	3	0	0.000	0.000
10	7/13/93	10:59	0.027	53.5	76.6	24	5	3	0	0.000	0.000
1	7/13/93	11:21	20.942	54.4	76.7	25	5	4	0	29.158	0.000
2	7/13/93	11:28	1.706	53.7	76.6	25	5	4	0	0.000	0.000
3	7/13/93	11:35	0.778	53.6	76.6	25	5	4	0	0.000	0.000
4	7/13/93	11:42	0.382	53.7	76.6	25	5	4	0	0.000	0.000
5	7/13/93	11:49	0.220	53.8	76.6	25	5	4	0	0.000	0.000
6	7/13/93	11:56	0.143	53.7	76.7	25	5	4	0	0.000	0.000
7	7/13/93	12:03	0.114	54.1	76.9	25	5	4	0	0.000	0.000
8	7/13/93	12:10	0.079	54.1	76.9	25	5	4	0	0.000	0.000
9	7/13/93	12:16	0.079	54.9	77.2	25	5	4	0	0.000	0.000
10	7/13/93	12:23	0.066	54.7	77.1	25	5	4	0	0.000	0.000
1	7/13/93	14:17	20.064	56.8	76.8	26	5	4	0	27.157	0.000
2	7/13/93	14:25	1.751	56.0	76.8	26	5	4	0	0.000	0.000
3	7/13/93	14:33	0.651	56.1	77.1	26	5	4	0	0.000	0.000
4	7/13/93	14:40	0.339	55.9	77.0	26	5	4	0	0.000	0.000
5	7/13/93	14:46	0.205	55.8	77.0	26	5	4	0	0.000	0.000
6	7/13/93	14:53	0.140	55.4	77.1	26	5	4	0	0.000	0.000
7	7/13/93	15:00	0.125	55.4	77.1	26	5	4	0	0.000	0.000
8	7/13/93	15:07	0.093	56.0	77.2	26	5	4	0	0.000	0.000
9	7/13/93	15:14	0.073	54.7	77.2	26	5	4	0	0.000	0.000
10	7/13/93	15:21	0.061	56.0	77.3	26	5	4	0	0.000	0.000
1	7/14/93	11:20	0.458	54.6	76.6	27	6	1	0	0.686	0.000
2	7/14/93	11:32	0.513	54.8	76.7	27	6	1	0	0.625	0.000
3	7/14/93	11:46	0.551	55.0	76.9	27	6	1	0	0.648	0.000
4	7/14/93	11:52	0.109	54.1	76.8	27	6	1	0	0.000	0.000
5	7/14/93	12:01	0.081	54.5	76.9	27	6	1	0	0.000	0.000
6	7/14/93	12:07	0.047	54.8	76.3	27	6	1	0	0.000	0.000

Table A-11: Data from Task 4 (continued)

Gravimetrics Data											
Run No	Date	Time	Diff (g)	RH (%)	Temp (F)	Bag No	Meas Type	Dust Amount	Amount Deposit (g)	Amount Ground-in (g)	Amount Picked by Wand (g)
1	7/14/93	14:48	0.503	53.2	77.1	28	6	1	0	0.657	0.000
2	7/14/93	14:56	0.533	53.0	77.2	28	6	1	0	0.669	0.000
3	7/14/93	15:04	0.573	53.5	77.2	28	6	1	0	0.675	0.000
4	7/14/93	15:11	0.081	53.0	77.3	28	6	1	0	0.000	0.000
5	7/14/93	15:18	0.055	52.9	77.3	28	6	1	0	0.000	0.000
6	7/14/93	15:25	0.034	53.0	77.4	28	6	1	0	0.000	0.000
7	7/14/93	15:32	0.032	52.9	77.5	28	6	1	0	0.000	0.000
8	7/14/93	15:38	0.030	53.0	77.5	28	6	1	0	0.000	0.000
9	7/14/93	15:45	0.021	52.7	77.6	28	6	1	0	0.000	0.000
10	7/14/93	15:58	0.026	52.8	77.6	28	6	1	0	0.000	0.000

A6.5 Develop and demonstrate a method for measuring exhaust emissions

Table A-12 consists of the data generated from Task 5. The description of the data in each column of Table A-12 is listed below:

Column Name	Description
Vac	Vacuum cleaner used in the test (either A, B, C or D)
Rep	Replication within vacuum cleaner
Date	Date the test was performed
Bag Wt	Initial weight of the vacuum cleaner bag
Net Dust Wt	Amount of dust deposited on the turntable
Gas Flow Rate	Actual flow rate of the air leaving the pitot tube
Rate Selected	Selected flow rate of the air leaving the pitot tube
Nozzle Size	Diameter of the nozzle
Time	Time the test was performed
Particulate Conc	Concentration of the dust leaving the encased vacuum cleaner
Final Bag Wt	Vacuum cleaner bag weight after all replications had been completed

Table A-12: Exhaust emissions data for Task 5

Gravimetric Data										
Vac	Rep	Date	Bag Wt (g)	Net Dust Wt (g)	Gas Flow Rate (acfm)	Rate Selected (L/min)	Nozzle Size (in)	Time (min)	Particulate Conc (mg/cu m)	Final Bag Wt (g)
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	0	0.021	41.481
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	1	0.066	41.481
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	2	.	41.481
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	3	.	41.481
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	4	.	41.481
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	5	.	41.481
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	6	.	41.481
A	1	7/27/93	36.756	4.9744	75.03	2.0	0.240	7	.	41.481
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	0	0.080	40.877
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	1	0.042	40.877
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	2	0.038	40.877
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	3	0.036	40.877
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	4	0.037	40.877
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	5	0.076	40.877
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	6	0.020	40.877
A	2	7/27/93	35.895	5.1020	75.03	2.0	0.240	7	0.041	40.877
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	0	0.078	40.381
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	1	0.040	40.381
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	2	0.035	40.381
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	3	0.032	40.381
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	4	0.033	40.381
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	5	0.035	40.381
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	6	0.032	40.381
A	3	7/27/93	35.452	5.0486	75.03	2.0	0.240	7	0.035	40.381
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	0	0.049	41.077
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	1	0.128	41.077
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	2	0.171	41.077
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	3	0.062	41.077
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	4	0.055	41.077
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	5	0.045	41.077
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	6	0.043	41.077
A	4	7/27/93	36.298	4.9632	75.03	2.0	0.240	7	0.060	41.077
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	0	0.015	40.944
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	1	0.018	40.944
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	2	0.037	40.944
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	3	0.034	40.944
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	4	0.030	40.944
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	5	0.020	40.944
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	6	0.016	40.944
B	1	7/28/93	36.092	5.0541	80.16	2.0	0.240	7	0.014	40.944
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	0	0.011	45.812

Table A-12: Exhaust emissions data for Task 5 (continued)

Gravimetric Data										
Vac	Rep	Date	Bag Wt (g)	Net Dust Wt (g)	Gas Flow Rate (acfm)	Rate Selected (L/min)	Nozzle Size (in)	Time (min)	Particulate Conc (mg/cu m)	Final Bag Wt (g)
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	1	0.013	45.812
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	2	0.024	45.812
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	3	0.017	45.812
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	4	0.017	45.812
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	5	0.022	45.812
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	6	0.011	45.812
B	2	7/28/93	40.869	5.0816	80.16	2.0	0.240	7	0.010	45.812
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	0	0.008	46.972
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	1	0.010	46.972
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	2	0.023	46.972
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	3	0.015	46.972
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	4	0.011	46.972
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	5	0.013	46.972
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	6	0.010	46.972
B	3	7/28/93	42.089	5.0012	80.16	2.0	0.240	7	0.009	46.972
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	0	0.004	35.098
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	1	0.003	35.098
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	2	0.003	35.098
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	3	0.003	35.098
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	4	0.003	35.098
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	5	0.003	35.098
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	6	0.003	35.098
C	1	7/28/93	30.210	5.1301	67.85	2.0	0.240	7	0.003	35.098
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	0	0.008	35.176
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	1	0.003	35.176
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	2	0.003	35.176
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	3	0.003	35.176
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	4	0.003	35.176
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	5	0.003	35.176
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	6	0.003	35.176
C	2	7/28/93	30.273	5.0403	67.85	2.0	0.240	7	0.003	35.176
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	0	0.005	36.049
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	1	0.003	36.049
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	2	0.002	36.049
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	3	0.003	36.049
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	4	0.003	36.049
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	5	0.003	36.049
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	6	0.003	36.049
C	3	7/28/93	31.111	5.0578	67.85	2.0	0.240	7	0.003	36.049
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	0	0.012	38.980
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	1	0.044	38.980

Table A-12: Exhaust emissions data for Task 5 (continued)

Gravimetric Data										
Vac	Rep	Date	Bag Wt (g)	Net Dust Wt (g)	Gas Flow Rate (acfm)	Rate Selected (L/min)	Nozzle Size (in)	Time (min)	Particulate Conc (mg/cu m)	Final Bag Wt (g)
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	2	0.266	38.980
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	3	0.152	38.980
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	4	0.210	38.980
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	5	0.136	38.980
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	6	0.021	38.980
D	1	7/29/93	34.383	4.9777	45.81	2.0	0.297	7	0.022	38.980
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	0	0.018	39.282
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	1	0.020	39.282
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	2	0.183	39.282
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	3	0.080	39.282
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	4	0.098	39.282
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	5	0.068	39.282
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	6	0.015	39.282
D	2	7/29/93	34.412	5.1199	45.81	2.0	0.297	7	0.016	39.282
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	0	0.013	36.396
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	1	0.017	36.396
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	2	0.180	36.396
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	3	0.128	36.396
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	4	0.093	36.396
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	5	0.170	36.396
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	6	0.013	36.396
D	3	7/29/93	34.593	5.0122	45.81	2.0	0.297	7	0.013	36.396

APPENDIX B: PRECONDITIONING DATA

B1 Fiber Preconditioning

Fiber preconditioning was performed to remove loose fibers from the carpet and upholstery samples which might adversely affect the measurements of dust recovery and lead concentration. The fiber preconditioning procedures are discussed in Section 4.3. Fiber preconditioning for carpets and upholstery were analyzed separately and are discussed in the following two subsections.

B1.1 Fiber Preconditioning on Carpets

The preconditioning tests determined the increase in weight of the vacuum cleaner bags when vacuuming the substrates for either 5 minute or, in a few cases, 40 seconds. The fiber preconditioning was performed on 8 carpet samples using all four vacuum cleaners. The data sheets identified each vacuum cleaner used and the substrate section. The number of vacuumings varied among the substrate samples and in some cases 40 second vacuumings were used to estimate fiber recovery under the conditions used in the study tests. Therefore, the data were summarized by calculating the cumulative weight gain for each five minute period of vacuuming (i.e. the period from 0 to 5 minutes, 5 to 10 minutes, 10 to 15, minutes of vacuuming, etc.). These estimates of five-minute weight gain were analyzed as a function of cumulative vacuuming time and other factors.

During the analysis, 5 outliers were identified, all using vacuum cleaner D. These outliers include the following points:

	Planned Substrate usage			
Substrate	Dust loading (mg/sq ft)	Nominal lead concentration	Vacuum cleaner	Cumulative minutes of vacuuming
Carpet	400	High	D	80
Carpet	400	High	D	140
Carpet	400	High	D	160
Carpet with Ground-in dust	400	Low	D	65
Carpet with Ground-in dust	400	High	D	20

Possible problems with the first reading of the day using vacuum cleaner D (the upright) had been noted. However, even after correcting for possible effects associated with the first vacuuming using vacuum cleaner D, there observations appeared to be distinct outliers (Because the analysis of the preconditioning data was not central to the study, to save time formal outlier tests were not performed).

A preliminary model was fit to the data with terms for the interaction between vacuum cleaner and substrate sample, minutes of vacuuming on the substrate sample, and indicator to identify the first measurement of the day using vacuum cleaner D. The least square estimates of the mean recovery versus cumulative vacuuming time are shown in Figure B-1. The preliminary analysis clearly indicates that the five-minute weight gain due to fibers from carpets decreases substantially within the first 20 seconds of vacuuming, after which it remains relatively constant over the next four hours of vacuuming.

Due to the variability in the weight gain measurements in the first 20 minutes of vacuuming among carpet samples and the change in 5-minute weight gain with time at the beginning of the preconditioning, the weight gain measurements in the first 20 minutes of vacuuming (the first vacuuming with each vacuum cleaner) were excluded from the final analysis of the fiber preconditioning data.

The final model fit a separate linear trend to the 5-minute weight gain as a function of cumulative vacuuming time for each substrate sample. The final model also had terms for differences among combinations of vacuum cleaner and substrate samples and the first vacuuming of the day using vacuum cleaner D. A weighted analysis was used, with the regression weights being a function of the substrate sample. All terms were highly significant ($p < 0.0001$) except for the differences among slopes for the different substrate samples ($p = 0.0383$). Weight gains were highest for vacuum cleaner D. There was no evidence for serial correlation among the residuals.

In the full study, the vacuum cleaner tests use 40 second vacuumings rather than the 5-minute vacuumings using in most of the fiber preconditioning. The final model was used to predict the fiber uptake in 40 seconds of vacuuming which might be seen in the full study by dividing the predicted 5-minute weight gain by 7.5. The predicted weight gain due to fibers is shown in Table 8-1, broken down by substrate, dust loading and nominal dust lead concentration (i.e., by individual substrate sample) and by the vacuum cleaner used on the sample. These values were used as possible covariates in the analysis of data from the vacuum cleaner and sampler tests.

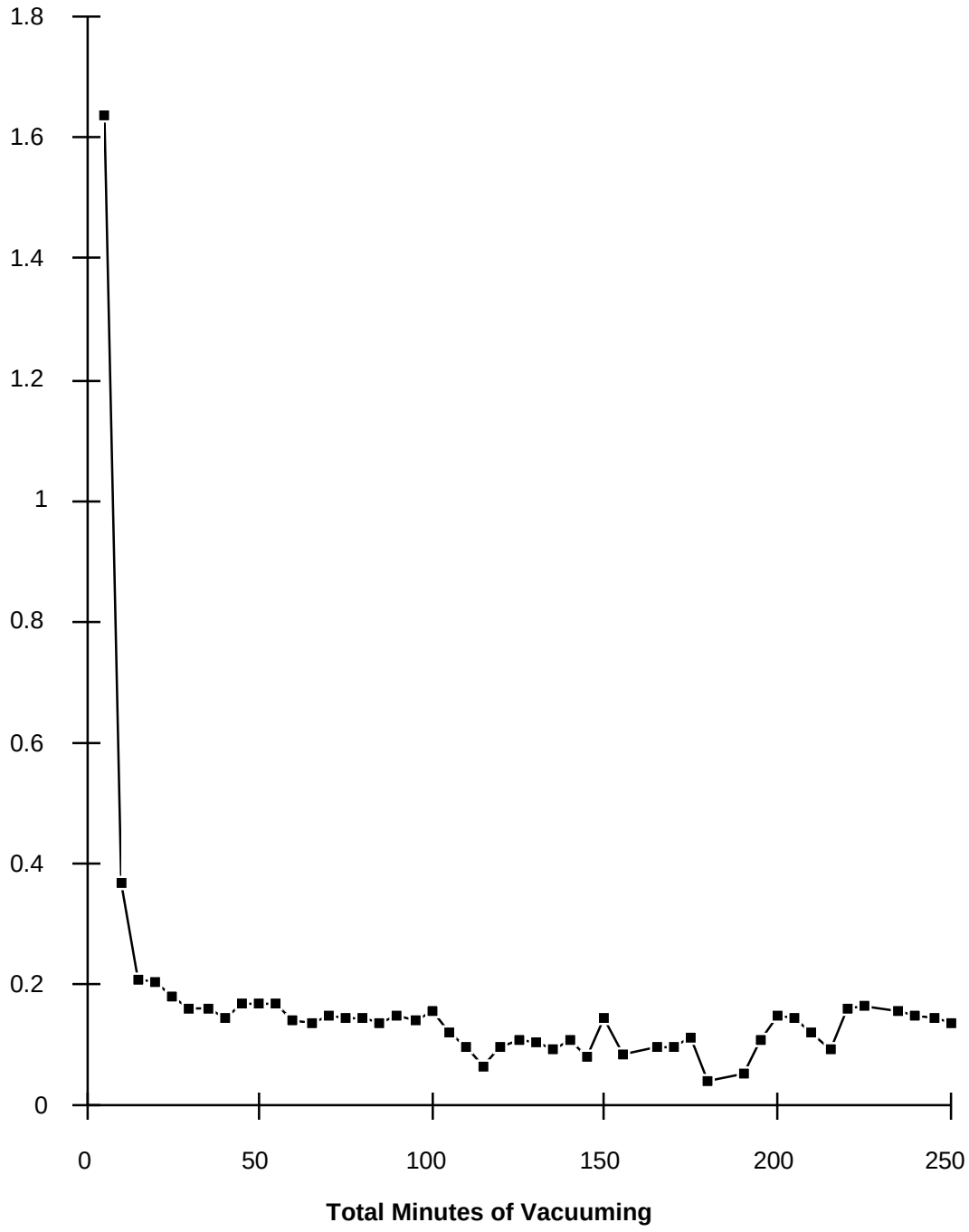


Figure B-1 Five minute weight gain due to fibers versus cumulative vacuuming time

B1.2 Fiber Preconditioning on Upholstery

The data provided by the preconditioning are the increase in weight of the vacuum cleaner bags when vacuuming the upholstery samples for 5 minutes. The fiber preconditioning was performed on 4 upholstery samples using all four vacuum cleaners. The data included indicators for the vacuum cleaner and substrate sample. Two samples were vacuumed for a total of 100 minutes and two for a total of 120 minutes. Three outliers, negative weight gains all of which were the from the first vacuuming of the day using vacuum cleaner D, were removed for the preliminary analysis. After determining that regression weights would improve the model, a fourth outlier was identified based on the weighted analysis (from the second vacuuming of the day using vacuum cleaner D). These outliers are summarized below.

	Planned Substrate Usage			
Substrate	Dust loading (mg/sq ft)	Nominal lead concentration	Vacuum cleaner	Cumulative minutes of vacuuming
Upholstery	100	High	D	45
Upholstery	400	Low	D	15
Upholstery	400	Low	D	75
Upholstery	400	High	D	80

Preliminary analysis, using two way analysis of variance, indicated that the weight gain due to fibers depended on the cumulative vacuuming time and the vacuum cleaner used. The predicted average five-minute weight gain (with its 95% confidence interval) as a function of time is shown in Figure B-2 (using dark circles). Except for the last four vacuumings, performed only on two of the four substrates, the weight gain appears to follow a decreasing curve. No reason has been found to explain the apparent change after 100 minutes of vacuuming. To provide balanced data for the analysis, only the data for the first 100 minutes of vacuuming were used in the final analysis.

Table B-1 Predicted 40-second fiber uptake from carpets by substrate sample and vacuum cleaner

Planned Substrate Usage				
Substrate	Vacuum cleaner	Dust loading (mg/sq ft)	Nominal dust lead concentration	Predicted weight of fibers/40sec (g)
Carpet	A	400	High	0.006
Carpet	B	400	High	0.001
Carpet	C	400	High	0.002
Carpet	D	400	High	0.005
Carpet	A	400	Low	0.003
Carpet	B	400	Low	-0.001
Carpet	C	400	Low	-0.004
Carpet	D	400	Low	0.013
Carpet	A	100	Low	0.002
Carpet	B	100	Low	-0.001
Carpet	C	100	Low	0.001
Carpet	D	100	Low	0.004
Carpet	A	100	High	0.005
Carpet	B	100	High	0.001
Carpet	C	100	High	0.001
Carpet	D	100	High	0.01
Carpet w Grind-in	A	100	Low	0.003
Carpet w Grind-in	B	100	Low	-0.002
Carpet w Grind-in	C	100	Low	0.001
Carpet w Grind-in	D	100	Low	0.004
Carpet w Grind-in	A	100	High	0
Carpet w Grind-in	B	100	High	0.001
Carpet w Grind-in	C	100	High	0
Carpet w Grind-in	D	100	High	0.002
Carpet w Grind-in	A	400	Low	0.01
Carpet w Grind-in	B	400	Low	0.004
Carpet w Grind-in	C	400	Low	0.003
Carpet w Grind-in	D	400	Low	0.008
Carpet w Grind-in	A	400	High	-0.002
Carpet w Grind-in	B	400	High	-0.001
Carpet w Grind-in	C	400	High	-0.003
Carpet w Grind-in	D	400	High	0.021

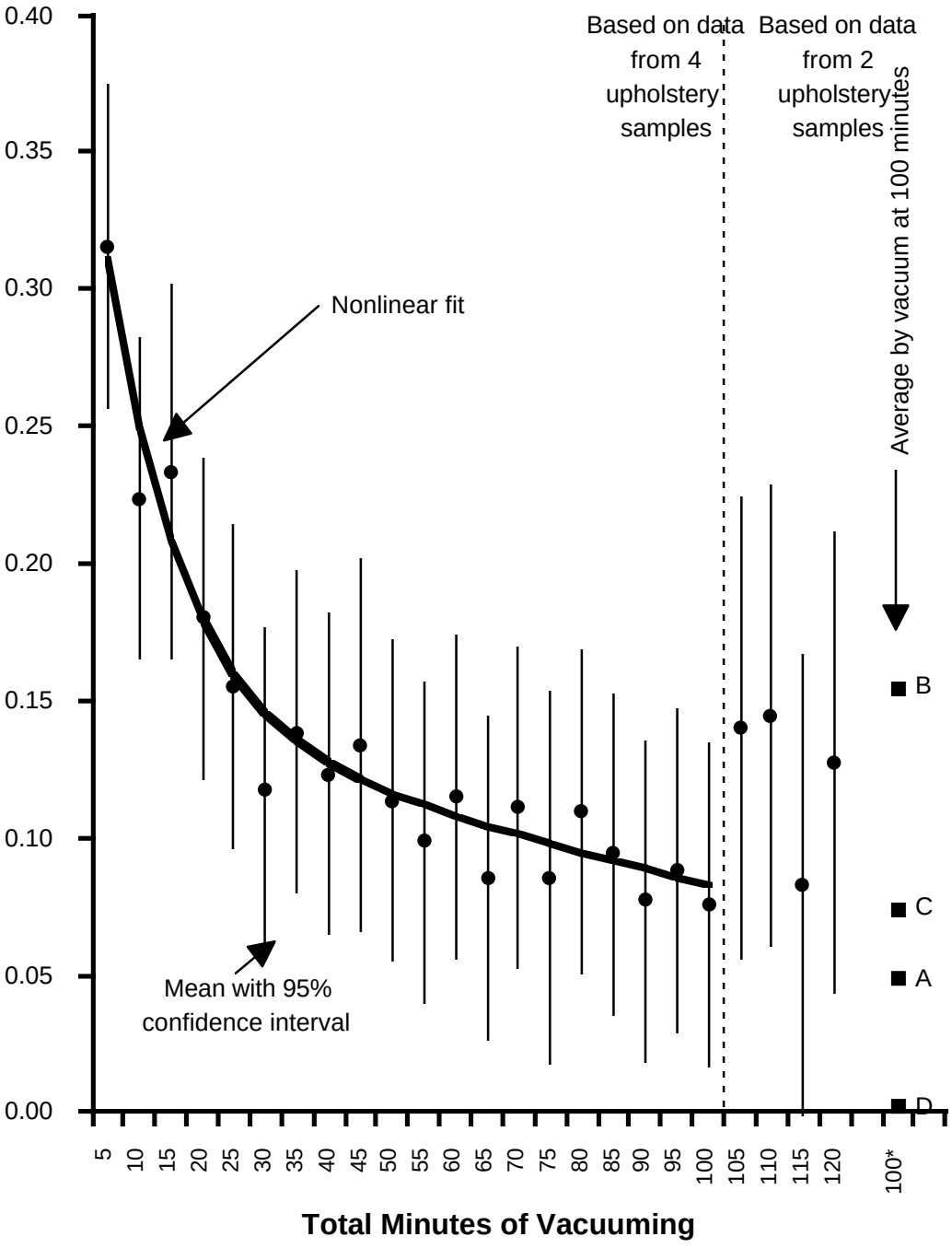


Figure B-2 Five minute weight gain due to fiber as a function of cumulative vacuuming time; predicted means (with 95% confidence intervals) and trend (non-linear curve)

Several relationships to describe the trend in the weight gain as a function of time were considered. The following non-linear model incorporating an exponential decay and a linear trend provided the best and most parsimonious description of the overall trend:

Weight gain = Z * exp(-R * Minutes-of-vacuuming) + constant + slope * Minutes-of-vacuuming

The predicted values from the non-linear model were used in regression to identify the final model for the data. Due to concern for unequal measurement variance, regression weights were determined using the procedures in Section 6.2. The measurement variance was found to depend on the predicted weight gain, with larger variance associated with larger predicted weight gain.

The final weighted model had terms for time, represented by the predicted non-linear relationship, vacuum cleaner and sample. Because the predicted non-linear relationship had four parameters, the degrees of freedom for error was slightly biased, however this had little effect on the results, all terms were statistically significant at the 2% level or better. The least square estimated of average five minute weight gain by vacuum are shown on the right side of Figure B-2. The corresponding averages for substrates samples were more similar, i.e., showed less variation, than for the vacuum cleaners. On upholstery, vacuum cleaner D collected fewer fibers than other vacuum cleaners, unlike for carpets. This difference is due in part to the differences in the beater bar attachments used to vacuum carpets and the upholstery attachments used with the upholstery samples. After the first half hour of vacuuming upholstery, the weight gain due to fibers decreases slowly with increasing vacuuming

The predicted 40-seconds weight gain due to fibers was calculated for each of the substrates and vacuum cleaners and is shown in Table B-2 These values were used as possible covariates in the analysis of data from the vacuum cleaner and sampler tests. The predicted values are based on the first 100 minutes of vacuuming and apply to the vacuum cleaner and sampler tests assuming the measurements for cumulative vacuuming times from 100 to 120 minutes do not represent the weight gain at later times. Even if this assumption is not correct, the effect of the study results are expected to be very small.

Table B-2 Predicted 40-second fiber uptake from upholstery by substrate sample and vacuum cleaner

Vacuum cleaner	Dust loading (mg/sq ft)	Nominal dust lead concentration	Predicted Fibers/40sec (g)
A	100	High	0.009
A	400	High	0.004
A	400	Low	0.006
A	100	Low	0.007
B	100	High	0.023
B	400	High	0.018
B	400	Low	0.02
B	100	Low	0.021
C	100	High	0.012
C	400	High	0.008
C	400	Low	0.009
C	100	Low	0.01
D	100	High	0.003
D	400	High	-0.002
D	400	Low	0
D	100	Low	0

B1.3 Fiber Preconditioning Data

Table B-3 consists of the fiber preconditioning data used in the preconditioning analysis. The description of the data in each column of Table B-3 is listed below:

Column name	Description
Sample	Sample number
Team	Team responsible for performing the test
Grindin	Whether the dust was ground in or not
Amount	Amount of dust applied (100 or 400 mg/sq ft)
Pb Conc	Nominal lead concentration (HIGH or LOW)
Wt Gain	Increase (g) from the vacuuming
Housevac	Vacuum cleaner used in the test
Date	Date of the test
Vac Min	Cumulative number of minutes vacuumed
Substrate	Substrate used in the test

The procedure for generating the data in Table B-3 follows:

1) Put a new bag in each vacuum each morning
2) For new bag, run vacuum for 5 min, wait 3 min and record weight. For used bag, used last weight
3) Cycle through the vacuums in order A,B,C,D,A,B,C,D,A,B... (depending on which vacuum cleaner was the initial vacuum cleaner)
4) Vacuum the substrate for 5 min, remove the bag, wait 3 min, weigh the bag
5) Calculate the increase in weight since the last weighing of the same bag
6) Cycle through the vacuums until two successive vacuums collect less than 20 mg of dust in 5 min

Table B-3: Fiber Preconditioning Data

Gravimetrics Data									
Sample	Team	Grindin	Amount (mg/sq ft)	Pb Conc	Wt Gain (g)	Housevac	Date	Vac Min	Substrate
Sample 1	1	NO	400	HIGH	1.809	A	7/30/93	5	Carpet
Sample 1	1	NO	400	HIGH	0.147	B	7/30/93	10	Carpet
Sample 1	1	NO	400	HIGH	0.050	C	7/30/93	15	Carpet
Sample 1	1	NO	400	HIGH	0.429	D	7/30/93	20	Carpet
Sample 1	1	NO	400	HIGH	0.134	A	7/30/93	25	Carpet
Sample 1	1	NO	400	HIGH	0.080	B	7/30/93	30	Carpet
Sample 1	1	NO	400	HIGH	0.056	C	7/30/93	35	Carpet
Sample 1	1	NO	400	HIGH	0.050	D	7/30/93	40	Carpet
Sample 1	1	NO	400	HIGH	0.115	A	7/30/93	45	Carpet
Sample 1	1	NO	400	HIGH	0.044	B	7/30/93	50	Carpet
Sample 1	1	NO	400	HIGH	0.020	C	7/30/93	55	Carpet
Sample 1	1	NO	400	HIGH	0.138	D	7/30/93	60	Carpet
Sample 1	1	NO	400	HIGH	0.097	A	7/30/93	65	Carpet
Sample 1	1	NO	400	HIGH	0.039	B	7/30/93	70	Carpet
Sample 1	1	NO	400	HIGH	0.010	C	7/30/93	75	Carpet
Sample 1	1	NO	400	HIGH	-0.129	D	7/30/93	80	Carpet
Sample 1	1	NO	400	HIGH	0.062	A	7/30/93	85	Carpet
Sample 1	1	NO	400	HIGH	0.085	B	7/30/93	90	Carpet
Sample 1	1	NO	400	HIGH	0.075	C	7/30/93	95	Carpet
Sample 1	1	NO	400	HIGH	0.196	D	7/30/93	100	Carpet
Sample 1	1	NO	400	HIGH	0.065	A	7/30/93	105	Carpet
Sample 1	1	NO	400	HIGH	0.013	B	7/30/93	110	Carpet
Sample 1	1	NO	400	HIGH	0.038	C	7/30/93	115	Carpet
Sample 1	1	NO	400	HIGH	0.268	D	7/30/93	120	Carpet
Sample 1	1	NO	400	HIGH	0.049	A	7/30/93	125	Carpet
Sample 1	1	NO	400	HIGH	-0.062	B	7/30/93	130	Carpet
Sample 1	1	NO	400	HIGH	-0.008	C	7/30/93	135	Carpet
Sample 1	1	NO	400	HIGH	-0.348	D	7/30/93	140	Carpet
Sample 1	1	NO	400	HIGH	-0.016	A	7/30/93	145	Carpet
Sample 1	1	NO	400	HIGH	-0.002	B	7/30/93	150	Carpet
Sample 1	1	NO	400	HIGH	0.009	C	7/30/93	155	Carpet
Sample 1	1	NO	400	HIGH	0.546	D	7/30/93	160	Carpet
Sample 1	1	NO	400	HIGH	0.030	A	7/30/93	165	Carpet
Sample 1	1	NO	400	HIGH	-0.005	B	7/30/93	170	Carpet
Sample 1	1	NO	400	HIGH	0.007	C	7/30/93	175	Carpet
Sample 1	1	NO	400	HIGH	0.184	D	7/30/93	180	Carpet
Sample 1	1	NO	400	HIGH	-0.013	A	8/3/93	190.33	Carpet
Sample 1	1	NO	400	HIGH	-0.013	B	8/3/93	195.33	Carpet
Sample 1	1	NO	400	HIGH	0.033	C	8/3/93	200.33	Carpet
Sample 1	1	NO	400	HIGH	0.070	D	8/3/93	205.33	Carpet
Sample 1	1	NO	400	HIGH	0.058	A	8/3/93	210.33	Carpet
Sample 1	1	NO	400	HIGH	-0.028	B	8/3/93	215.33	Carpet
Sample 1	1	NO	400	HIGH	0.045	C	8/3/93	220.33	Carpet
Sample 1	1	NO	400	HIGH	0.090	D	8/3/93	225.33	Carpet
Sample 1	1	NO	400	HIGH	0.093	A	8/4/93	235.67	Carpet
Sample 1	1	NO	400	HIGH	0.027	B	32723	240.67	Carpet
Sample 1	1	NO	400	HIGH	0.029	C	32723	245.67	Carpet
Sample 1	1	NO	400	HIGH	0.060	D	8/4/93	250.67	Carpet
Sample 2	2	NO	400	LOW	2.266	B	7/30/93	5	Carpet
Sample 2	2	NO	400	LOW	0.125	C	7/30/93	10	Carpet
Sample 2	2	NO	400	LOW	0.668	D	7/30/93	15	Carpet
Sample 2	2	NO	400	LOW	0.302	A	7/30/93	20	Carpet
Sample 2	2	NO	400	LOW	0.081	B	7/30/93	25	Carpet
Sample 2	2	NO	400	LOW	0.026	C	7/30/93	30	Carpet

Table B-3: Fiber Preconditioning Data (continued)

Gravimetrics Data									
Sample	Team	Grindin	Amount (mg/sq ft)	Pb Conc	WtGain (g)	Housevac	Date	VacMin	Substrate
Sample 2	2	NO	400	LOW	0.471	D	7/30/93	35	Carpet
Sample 2	2	NO	400	LOW	0.170	A	7/30/93	40	Carpet
Sample 2	2	NO	400	LOW	0.117	B	7/30/93	45	Carpet
Sample 2	2	NO	400	LOW	0.035	C	7/30/93	50	Carpet
Sample 2	2	NO	400	LOW	0.529	D	7/30/93	55	Carpet
Sample 2	2	NO	400	LOW	0.088	A	7/30/93	60	Carpet
Sample 2	2	NO	400	LOW	0.061	B	7/30/93	65	Carpet
Sample 2	2	NO	400	LOW	0.001	C	7/30/93	70	Carpet
Sample 2	2	NO	400	LOW	0.363	D	7/30/93	75	Carpet
Sample 2	2	NO	400	LOW	0.104	A	7/30/93	80	Carpet
Sample 2	2	NO	400	LOW	0.079	B	7/30/93	85	Carpet
Sample 2	2	NO	400	LOW	0.003	C	7/30/93	90	Carpet
Sample 2	2	NO	400	LOW	0.313	D	7/30/93	95	Carpet
Sample 2	2	NO	400	LOW	0.132	A	7/30/93	100	Carpet
Sample 2	2	NO	400	LOW	0.052	B	7/30/93	105	Carpet
Sample 2	2	NO	400	LOW	-0.009	C	7/30/93	110	Carpet
Sample 2	2	NO	400	LOW	0.145	D	7/30/93	115	Carpet
Sample 2	2	NO	400	LOW	0.061	A	7/30/93	120	Carpet
Sample 2	2	NO	400	LOW	0.026	B	7/30/93	125	Carpet
Sample 2	2	NO	400	LOW	0.071	C	7/30/93	130	Carpet
Sample 2	2	NO	400	LOW	0.027	D	7/30/93	135	Carpet
Sample 2	2	NO	400	LOW	0.031	A	7/30/93	140	Carpet
Sample 2	2	NO	400	LOW	0.000	B	7/30/93	145	Carpet
Sample 2	2	NO	400	LOW	0.129	C	7/30/93	150	Carpet
Sample 2	2	NO	400	LOW	0.037	D	7/30/93	155	Carpet
Sample 2	2	NO	400	LOW	0.045	B	8/4/93	165.33	Carpet
Sample 2	2	NO	400	LOW	0.030	C	8/4/93	170.33	Carpet
Sample 2	2	NO	400	LOW	0.100	D	8/4/93	175.33	Carpet
Sample 2	2	NO	400	LOW	0.041	A	8/4/93	180.33	Carpet
Sample 3	2	NO	100	LOW	2.322	C	8/4/93	5	Carpet
Sample 3	2	NO	100	LOW	0.378	D	8/4/93	10	Carpet
Sample 3	2	NO	100	LOW	0.088	A	8/4/93	15	Carpet
Sample 3	2	NO	100	LOW	0.021	B	8/4/93	20	Carpet
Sample 3	2	NO	100	LOW	0.023	C	8/4/93	25	Carpet
Sample 3	2	NO	100	LOW	0.059	D	8/4/93	30	Carpet
Sample 3	2	NO	100	LOW	0.000	A	8/4/93	35	Carpet
Sample 3	2	NO	100	LOW	0.009	B	8/4/93	40	Carpet
Sample 3	2	NO	100	LOW	0.061	C	8/5/93	49.67	Carpet
Sample 3	2	NO	100	LOW	0.056	D	8/5/93	54.67	Carpet
Sample 3	2	NO	100	LOW	0.018	A	8/5/93	59.67	Carpet
Sample 3	2	NO	100	LOW	0.014	B	8/5/93	64.67	Carpet
Sample 3	2	NO	100	LOW	0.005	C	8/5/93	69.67	Carpet
Sample 3	2	NO	100	LOW	0.056	D	8/5/93	74.67	Carpet
Sample 3	2	NO	100	LOW	-0.002	A	8/5/93	79.67	Carpet
Sample 3	2	NO	100	LOW	0.018	B	8/5/93	84.67	Carpet
Sample 3	2	NO	100	LOW	0.019	C	8/5/93	89.67	Carpet
Sample 3	2	NO	100	LOW	0.025	D	8/6/93	94.67	Carpet
Sample 3	2	NO	100	LOW	0.020	A	8/9/93	99.67	Carpet
Sample 3	2	NO	100	LOW	-0.013	B	8/9/93	104.67	Carpet
Sample 3	2	NO	100	LOW	0.023	C	8/9/93	109.67	Carpet
Sample 3	2	NO	100	LOW	0.008	D	8/9/93	114.67	Carpet
Sample 3	2	NO	100	LOW	0.028	A	8/9/93	119.67	Carpet
Sample 3	2	NO	100	LOW	0.001	B	8/9/93	124.67	Carpet
Sample 3	2	NO	100	LOW	-0.014	C	8/9/93	129.67	Carpet

Table B-3: Fiber Preconditioning Data (continued)

Gravimetrics Data									
Sample	Team	Grindin	Amount (mg/sq ft)	Pb Conc	WtGain (g)	Housevac	Date	VacMin	Substrate
Sample 3	2	NO	100	LOW	0.046	D	8/9/93	134.67	Carpet
Sample 3	2	NO	100	LOW	0.060	A	8/9/93	139.67	Carpet
Sample 3	2	NO	100	LOW	-0.029	B	8/9/93	144.67	Carpet
Sample 4	1	NO	100	HIGH	0.980	D	8/4/93	5	Carpet
Sample 4	1	NO	100	HIGH	0.563	A	8/4/93	10	Carpet
Sample 4	1	NO	100	HIGH	0.008	B	8/4/93	15	Carpet
Sample 4	1	NO	100	HIGH	0.045	C	8/4/93	20	Carpet
Sample 4	1	NO	100	HIGH	0.152	D	8/4/93	25	Carpet
Sample 4	1	NO	100	HIGH	0.088	A	8/4/93	30	Carpet
Sample 4	1	NO	100	HIGH	0.010	B	8/4/93	35	Carpet
Sample 4	1	NO	100	HIGH	0.005	C	8/4/93	40	Carpet
Sample 4	1	NO	100	HIGH	0.125	D	8/4/93	47.67	Carpet
Sample 4	1	NO	100	HIGH	0.048	A	8/4/93	52.67	Carpet
Sample 4	1	NO	100	HIGH	0.001	B	8/4/93	57.67	Carpet
Sample 4	1	NO	100	HIGH	0.021	C	8/4/93	62.67	Carpet
Sample 4	1	NO	100	HIGH	0.095	D	8/6/93	67.67	Carpet
Sample 4	1	NO	100	HIGH	0.042	A	8/6/93	72.67	Carpet
Sample 4	1	NO	100	HIGH	0.007	B	8/6/93	77.67	Carpet
Sample 4	1	NO	100	HIGH	0.023	C	8/6/93	82.67	Carpet
Sample 4	1	NO	100	HIGH	0.097	D	8/6/93	87.67	Carpet
Sample 4	1	NO	100	HIGH	0.055	A	8/6/93	92.67	Carpet
Sample 4	1	NO	100	HIGH	0.055	B	8/9/93	97.67	Carpet
Sample 4	1	NO	100	HIGH	0.027	C	8/9/93	102.67	Carpet
Sample 4	1	NO	100	HIGH	0.011	D	8/9/93	107.67	Carpet
Sample 4	1	NO	100	HIGH	0.024	A	8/9/93	112.67	Carpet
Sample 4	1	NO	100	HIGH	-0.008	B	8/9/93	117.67	Carpet
Sample 4	1	NO	100	HIGH	0.015	C	8/9/93	122.67	Carpet
Sample 4	1	NO	100	HIGH	0.063	D	8/9/93	127.67	Carpet
Sample 4	1	NO	100	HIGH	0.045	A	8/9/93	132.67	Carpet
Sample 4	1	NO	100	HIGH	0.060	B	8/9/93	137.67	Carpet
Sample 4	1	NO	100	HIGH	0.014	C	8/9/93	142.67	Carpet
Sample 5	1	YES	100	LOW	0.786	B	8/5/93	5	Carpet
Sample 5	1	YES	100	LOW	0.035	C	8/5/93	10	Carpet
Sample 5	1	YES	100	LOW	0.103	D	8/5/93	15	Carpet
Sample 5	1	YES	100	LOW	0.033	A	8/5/93	20	Carpet
Sample 5	1	YES	100	LOW	0.007	B	8/5/93	25	Carpet
Sample 5	1	YES	100	LOW	0.009	C	8/5/93	30	Carpet
Sample 5	1	YES	100	LOW	0.065	D	8/5/93	35	Carpet
Sample 5	1	YES	100	LOW	0.041	A	8/5/93	40	Carpet
Sample 5	1	YES	100	LOW	0.001	B	8/5/93	45	Carpet
Sample 5	1	YES	100	LOW	0.014	C	8/5/93	50	Carpet
Sample 5	1	YES	100	LOW	0.041	D	8/5/93	55	Carpet
Sample 5	1	YES	100	LOW	0.023	A	8/5/93	60	Carpet
Sample 5	1	YES	100	LOW	-0.029	B	8/6/93	65	Carpet
Sample 5	1	YES	100	LOW	0.020	C	8/6/93	70	Carpet
Sample 5	1	YES	100	LOW	0.010	D	8/6/93	75	Carpet
Sample 5	1	YES	100	LOW	0.017	A	8/6/93	80	Carpet
Sample 5	1	YES	100	LOW	0.009	B	8/6/93	85	Carpet
Sample 5	1	YES	100	LOW	0.025	C	8/6/93	90	Carpet
Sample 5	1	YES	100	LOW	0.027	D	8/6/93	95	Carpet
Sample 5	1	YES	100	LOW	0.034	A	8/6/93	100	Carpet
Sample 6	2	YES	100	HIGH	1.092	C	8/5/93	5	Carpet
Sample 6	2	YES	100	HIGH	0.575	D	8/5/93	10	Carpet
Sample 6	2	YES	100	HIGH	0.029	A	8/5/93	15	Carpet

Table B-3: Fiber **Preconditioning Data** (continued)

Gravimetrics Data									
Sample	Team	Grindin	Amount (mg/sq ft)	Pb Conc	WtGain (g)	Housevac	Date	VacMin	Substrate
Sample 6	2	YES	100	HIGH	-0.023	B	8/5/93	20	Carpet
Sample 6	2	YES	100	HIGH	0.023	C	8/5/93	25	Carpet
Sample 6	2	YES	100	HIGH	0.037	D	8/5/93	30	Carpet
Sample 6	2	YES	100	HIGH	0.020	A	8/5/93	35	Carpet
Sample 6	2	YES	100	HIGH	0.011	B	8/5/93	40	Carpet
Sample 6	2	YES	100	HIGH	0.019	C	8/5/93	45	Carpet
Sample 6	2	YES	100	HIGH	0.044	D	8/5/93	50	Carpet
Sample 6	2	YES	100	HIGH	0.013	A	8/5/93	55	Carpet
Sample 6	2	YES	100	HIGH	0.033	B	8/5/93	60	Carpet
Sample 6	2	YES	100	HIGH	0.006	C	8/6/93	65	Carpet
Sample 6	2	YES	100	HIGH	-0.017	D	8/6/93	70	Carpet
Sample 6	2	YES	100	HIGH	-0.017	A	8/6/93	75	Carpet
Sample 6	2	YES	100	HIGH	0.011	B	8/6/93	80	Carpet
Sample 6	2	YES	100	HIGH	0.007	C	8/6/93	85	Carpet
Sample 6	2	YES	100	HIGH	0.038	D	8/6/93	90	Carpet
Sample 6	2	YES	100	HIGH	0.016	A	8/6/93	95	Carpet
Sample 6	2	YES	100	HIGH	-0.002	B	8/6/93	100	Carpet
Sample 7	1	YES	400	LOW	0.979	D	8/10/93	5	Carpet
Sample 7	1	YES	400	LOW	0.196	A	8/10/93	10	Carpet
Sample 7	1	YES	400	LOW	0.039	B	8/10/93	15	Carpet
Sample 7	1	YES	400	LOW	0.058	C	8/10/93	20	Carpet
Sample 7	1	YES	400	LOW	0.093	D	8/10/93	25	Carpet
Sample 7	1	YES	400	LOW	0.065	A	8/10/93	30	Carpet
Sample 7	1	YES	400	LOW	0.027	B	8/10/93	35	Carpet
Sample 7	1	YES	400	LOW	0.024	C	8/10/93	40	Carpet
Sample 7	1	YES	400	LOW	0.058	D	8/10/93	45	Carpet
Sample 7	1	YES	400	LOW	0.074	A	8/10/93	50	Carpet
Sample 7	1	YES	400	LOW	0.017	B	8/10/93	55	Carpet
Sample 7	1	YES	400	LOW	0.019	C	8/10/93	60	Carpet
Sample 7	1	YES	400	LOW	-0.104	D	8/11/93	65	Carpet
Sample 7	1	YES	400	LOW	0.142	A	8/11/93	70	Carpet
Sample 7	1	YES	400	LOW	0.092	B	8/11/93	75	Carpet
Sample 7	1	YES	400	LOW	0.019	C	8/11/93	80	Carpet
Sample 7	1	YES	400	LOW	0.047	D	8/11/93	85	Carpet
Sample 7	1	YES	400	LOW	0.043	A	8/11/93	90	Carpet
Sample 7	1	YES	400	LOW	0.013	B	8/11/93	95	Carpet
Sample 7	1	YES	400	LOW	0.034	C	8/11/93	100	Carpet
Sample 8	2	YES	400	HIGH	2.000	A	8/10/93	5	Carpet
Sample 8	2	YES	400	HIGH	0.087	B	8/10/93	10	Carpet
Sample 8	2	YES	400	HIGH	0.034	C	8/10/93	15	Carpet
Sample 8	2	YES	400	HIGH	0.323	D	8/10/93	20	Carpet
Sample 8	2	YES	400	HIGH	0.086	A	8/10/93	25	Carpet
Sample 8	2	YES	400	HIGH	0.075	B	8/10/93	30	Carpet
Sample 8	2	YES	400	HIGH	-0.003	C	8/10/93	35	Carpet
Sample 8	2	YES	400	HIGH	0.208	D	8/10/93	40	Carpet
Sample 8	2	YES	400	HIGH	0.029	A	8/10/93	45	Carpet
Sample 8	2	YES	400	HIGH	0.044	B	8/10/93	50	Carpet
Sample 8	2	YES	400	HIGH	0.026	C	8/10/93	55	Carpet
Sample 8	2	YES	400	HIGH	0.222	D	8/10/93	60	Carpet
Sample 8	2	YES	400	HIGH	0.002	A	8/11/93	65	Carpet
Sample 8	2	YES	400	HIGH	0.016	B	8/11/93	70	Carpet
Sample 8	2	YES	400	HIGH	0.019	C	8/11/93	75	Carpet
Sample 8	2	YES	400	HIGH	0.134	D	8/11/93	80	Carpet
Sample 8	2	YES	400	HIGH	-0.035	A	8/11/93	85	Carpet

Table B-3: Fiber Preconditioning Data (continued)

Gravimetrics Data									
Sample	Team	Grindin	Amount (mg/sq ft)	Pb Conc	WtGain (g)	Housevac	Date	VacMin	Substrate
Sample 8	2	YES	400	HIGH	-0.033	B	8/11/93	90	Carpet
Sample 8	2	YES	400	HIGH	-0.002	C	8/11/93	95	Carpet
Sample 8	2	YES	400	HIGH	0.188	D	8/11/93	100	Carpet
Sample 9	2	NO	100	LOW	0.219	C	8/12/93	5	Upholstery
Sample 9	2	NO	100	LOW	0.105	D	8/12/93	10	Upholstery
Sample 9	2	NO	100	LOW	0.240	A	8/12/93	15	Upholstery
Sample 9	2	NO	100	LOW	0.409	B	8/12/93	20	Upholstery
Sample 9	2	NO	100	LOW	0.139	C	8/12/93	25	Upholstery
Sample 9	2	NO	100	LOW	0.056	D	8/12/93	30	Upholstery
Sample 9	2	NO	100	LOW	0.141	A	8/12/93	35	Upholstery
Sample 9	2	NO	100	LOW	0.186	B	8/12/93	40	Upholstery
Sample 9	2	NO	100	LOW	0.177	C	8/13/93	45	Upholstery
Sample 9	2	NO	100	LOW	-0.007	D	8/13/93	50	Upholstery
Sample 9	2	NO	100	LOW	0.064	A	8/13/93	55	Upholstery
Sample 9	2	NO	100	LOW	0.151	B	8/13/93	60	Upholstery
Sample 9	2	NO	100	LOW	0.087	C	8/13/93	65	Upholstery
Sample 9	2	NO	100	LOW	0.077	D	8/13/93	70	Upholstery
Sample 9	2	NO	100	LOW	0.100	A	8/13/93	75	Upholstery
Sample 9	2	NO	100	LOW	0.161	B	8/13/93	80	Upholstery
Sample 9	2	NO	100	LOW	0.094	C	8/13/93	85	Upholstery
Sample 9	2	NO	100	LOW	0.047	D	8/13/93	90	Upholstery
Sample 9	2	NO	100	LOW	0.070	A	8/13/93	95	Upholstery
Sample 9	2	NO	100	LOW	0.182	B	8/13/93	100	Upholstery
Sample 9	2	NO	100	LOW	0.118	C	8/13/93	105	Upholstery
Sample 9	2	NO	100	LOW	0.095	D	8/13/93	110	Upholstery
Sample 9	2	NO	100	LOW	0.058	A	8/13/93	115	Upholstery
Sample 9	2	NO	100	LOW	0.240	B	8/13/93	120	Upholstery
Sample 10	1	NO	100	HIGH	0.170	D	8/12/93	5	Upholstery
Sample 10	1	NO	100	HIGH	0.272	A	8/12/93	10	Upholstery
Sample 10	1	NO	100	HIGH	0.333	B	8/12/93	15	Upholstery
Sample 10	1	NO	100	HIGH	0.170	C	8/12/93	20	Upholstery
Sample 10	1	NO	100	HIGH	0.138	D	8/12/93	25	Upholstery
Sample 10	1	NO	100	HIGH	0.181	A	8/12/93	30	Upholstery
Sample 10	1	NO	100	HIGH	0.222	B	8/12/93	35	Upholstery
Sample 10	1	NO	100	HIGH	0.172	C	8/12/93	40	Upholstery
Sample 10	1	NO	100	HIGH	-0.041	D	8/13/93	45	Upholstery
Sample 10	1	NO	100	HIGH	0.119	A	8/13/93	50	Upholstery
Sample 10	1	NO	100	HIGH	0.182	B	8/13/93	55	Upholstery
Sample 10	1	NO	100	HIGH	0.135	C	8/13/93	60	Upholstery
Sample 10	1	NO	100	HIGH	0.062	D	8/13/93	65	Upholstery
Sample 10	1	NO	100	HIGH	0.100	A	8/13/93	70	Upholstery
Sample 10	1	NO	100	HIGH	0.160	B	8/13/93	75	Upholstery
Sample 10	1	NO	100	HIGH	0.122	C	8/13/93	80	Upholstery
Sample 10	1	NO	100	HIGH	0.071	D	8/13/93	85	Upholstery
Sample 10	1	NO	100	HIGH	0.081	A	8/13/93	90	Upholstery
Sample 10	1	NO	100	HIGH	0.186	B	8/13/93	95	Upholstery
Sample 10	1	NO	100	HIGH	0.128	C	8/13/93	100	Upholstery
Sample 10	1	NO	100	HIGH	0.083	D	8/13/93	105	Upholstery
Sample 10	1	NO	100	HIGH	0.104	A	8/13/93	110	Upholstery
Sample 10	1	NO	100	HIGH	0.187	B	8/13/93	115	Upholstery
Sample 10	1	NO	100	HIGH	0.105	C	8/13/93	120	Upholstery
Sample 11	2	NO	400	HIGH	0.277	A	8/13/93	5	Upholstery
Sample 11	2	NO	400	HIGH	0.370	B	8/13/93	10	Upholstery
Sample 11	1	NO	400	HIGH	0.195	C	8/16/93	15	Upholstery

Table B-3: Fiber Preconditioning Data (continued)

Gravimetrics Data									
Sample	Team	Grindin	Amount (mg/sq ft)	Pb Conc	WtGain (g)	Housevac	Date	VacMin	Substrate
Sample 11	1	NO	400	HIGH	0.076	D	8/16/93	20	Upholstery
Sample 11	1	NO	400	HIGH	0.098	A	8/16/93	25	Upholstery
Sample 11	1	NO	400	HIGH	0.231	B	8/16/93	30	Upholstery
Sample 11	1	NO	400	HIGH	0.126	C	8/16/93	35	Upholstery
Sample 11	1	NO	400	HIGH	0.044	D	8/16/93	40	Upholstery
Sample 11	1	NO	400	HIGH	0.096	A	8/16/93	45	Upholstery
Sample 11	1	NO	400	HIGH	0.230	B	8/16/93	50	Upholstery
Sample 11	1	NO	400	HIGH	0.109	C	8/16/93	55	Upholstery
Sample 11	1	NO	400	HIGH	0.037	D	8/16/93	60	Upholstery
Sample 11	1	NO	400	HIGH	-0.011	A	8/16/93	65	Upholstery
Sample 11	1	NO	400	HIGH	0.172	B	8/16/93	70	Upholstery
Sample 11	1	NO	400	HIGH	0.064	C	8/17/93	75	Upholstery
Sample 11	1	NO	400	HIGH	0.142	D	8/17/93	80	Upholstery
Sample 11	1	NO	400	HIGH	0.043	A	8/17/93	85	Upholstery
Sample 11	1	NO	400	HIGH	0.105	B	8/17/93	90	Upholstery
Sample 11	1	NO	400	HIGH	0.096	C	8/17/93	95	Upholstery
Sample 11	1	NO	400	HIGH	-0.070	D	8/17/93	100	Upholstery
Sample 12	1	NO	400	LOW	0.596	B	8/13/93	5	Upholstery
Sample 12	1	NO	400	LOW	0.147	C	8/13/93	10	Upholstery
Sample 12	1	NO	400	LOW	-0.161	D	8/16/93	15	Upholstery
Sample 12	1	NO	400	LOW	0.065	A	8/16/93	20	Upholstery
Sample 12	1	NO	400	LOW	0.246	B	8/16/93	25	Upholstery
Sample 12	1	NO	400	LOW	0.004	C	8/16/93	30	Upholstery
Sample 12	1	NO	400	LOW	0.065	D	8/16/93	35	Upholstery
Sample 12	1	NO	400	LOW	0.091	A	8/16/93	40	Upholstery
Sample 12	1	NO	400	LOW	0.196	B	8/16/93	45	Upholstery
Sample 12	1	NO	400	LOW	0.112	C	8/16/93	50	Upholstery
Sample 12	1	NO	400	LOW	0.039	D	8/16/93	55	Upholstery
Sample 12	1	NO	400	LOW	0.137	A	8/16/93	60	Upholstery
Sample 12	1	NO	400	LOW	0.204	B	8/16/93	65	Upholstery
Sample 12	1	NO	400	LOW	0.096	C	8/16/93	70	Upholstery
Sample 12	1	NO	400	LOW	-0.148	D	8/17/93	75	Upholstery
Sample 12	1	NO	400	LOW	0.014	A	8/17/93	80	Upholstery
Sample 12	1	NO	400	LOW	0.169	B	8/17/93	85	Upholstery
Sample 12	1	NO	400	LOW	0.076	C	8/17/93	90	Upholstery
Sample 12	1	NO	400	LOW	0.000	D	8/17/93	95	Upholstery
Sample 12	1	NO	400	LOW	0.063	A	8/17/93	100	Upholstery

B2 Dust Preconditioning

Several vacuum cleaner and sampler tests were conducted using each substrate sample. To make the test conditions more similar between the first and last test on a substrate, dust was applied to each substrate and vacuumed off to simulate the previous tests. The weight of dust vacuumed from the substrate was determined, from which the dust recovery was calculated. The dust preconditioning procedures are discussed in Section 4.4. The dust preconditioning was done to all types of substrates and used all dust particle sizes and all vacuums on each substrate sample. This as done prior to use of substrates in any of the actual tests.

The dust preconditioning recovery data were analyzed separately for smooth substrates (tile, linoleum, wood) and rough substrates (carpet, carpet with grind-in, and upholstery). The initial model had factors for all two way interactions of substrate, nominal dust lead concentration, and dust loading, interaction of vacuum cleaner and dust loading, and all two way interactions of substrate, vacuum cleaner, and, for rough substrates, particle size. Terms which were not significant at the 5% level were eliminated from the model to determine the final model.

For dust preconditioning of smooth surfaces (tile, linoleum, wood), no factors were significant predictors of dust recovery. For rough substrates (carpet, carpet with grind-in, and upholstery), only the vacuum cleaner was a significant predictor of dust recovery. Differences in measurement variance among vacuum cleaners for rough substrates were not statistically significant. However, differences between rough and smooth substrates were significantly different. Therefore, the mean dust recovery and 95% confidence interval were calculated separately for each vacuum cleaner on rough substrates and for smooth substrates, without pooling the variance. Figure B-3 and Table B-4 show the average dust recovery for each vacuum cleaner on rough substrates and all vacuum cleaners on smooth substrates, with 95% confidence intervals. The pooled standard deviation for dust recovery measurements is 17%, greater than the 10% value assumed for the redesign of the study. Therefore, based on the dust preconditioning results, the full study may not achieve its data quality objectives.

The results show high dust recovery on smooth substrates (averaging 94% recovery). Recovery on rough substrates carpet and upholstery, depend on the vacuum cleaner used. For the canister vacuum cleaners, the highest dust recovery is found on the least expensive vacuum cleaner and the lowest dust recovery on the most expensive vacuum cleaner.

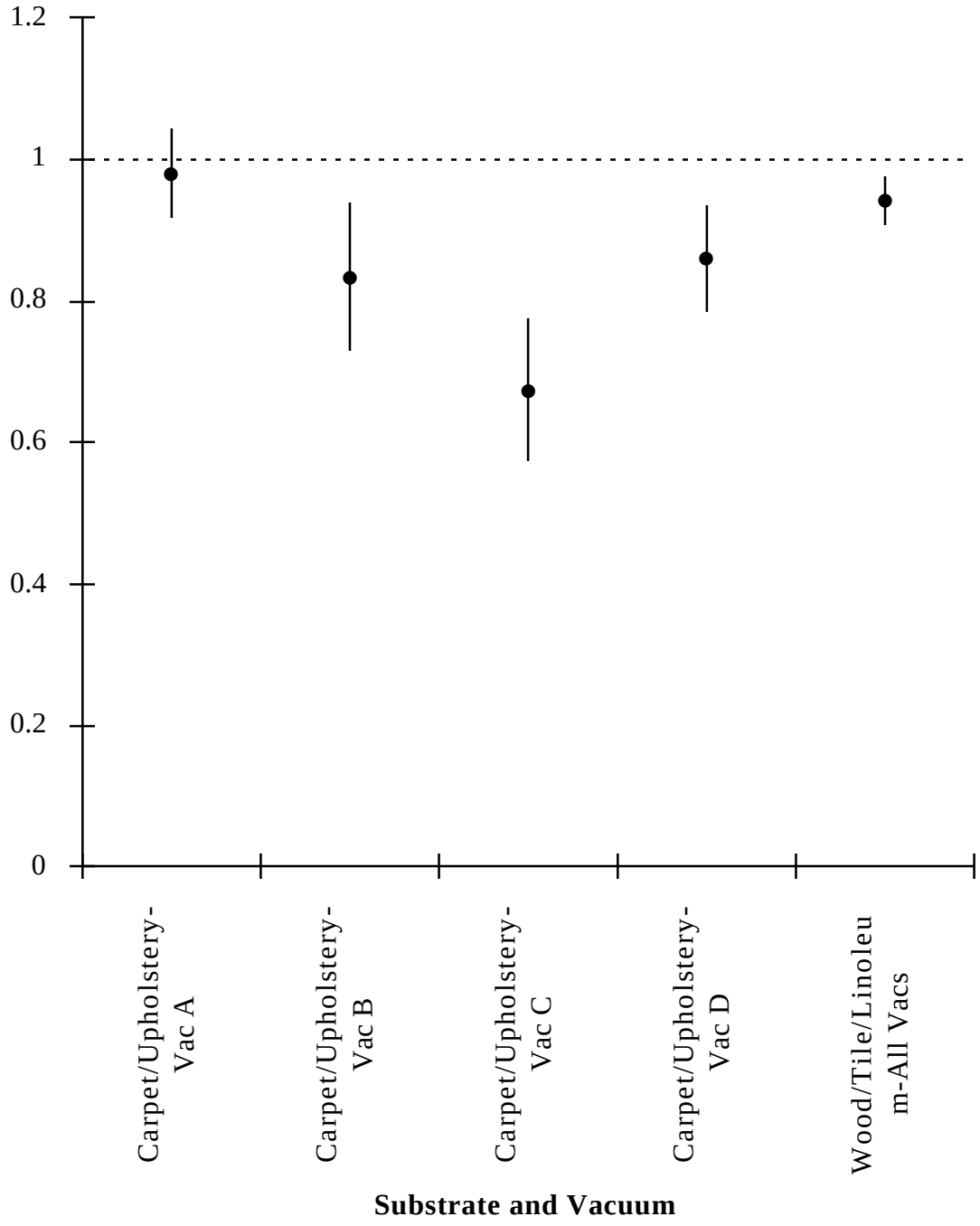


Figure B-3 Average preconditioning dust recovery by vacuum and substrate, with 95% confidence intervals

Table B-4 Average dust recovery by vacuum and substrate, with 95% confidence intervals

Substrate	Vacuum cleaner	Average dust recovery	95% confidence interval
Carpet/Upholstery	A	98%	92% to 104%
Carpet/Upholstery	B	83%	73% to 94%
Carpet/Upholstery	C	67%	57% to 77%
Carpet/Upholstery	D	86%	78% to 94%
Wood/Tile/Linoleum	All Vacs	94%	91% to 98%

B2.1 Dust Preconditioning Data

Table B-5 consists of the dust preconditioning data used in the preconditioning analysis. The description of the data in each column of Table B-5 is listed below:

Column Name	Description
Substrate	Substrate used in the test
Grind-in	Whether the dust was ground in (applies only to carpet and upholstery substrates)
Amount	Amount of dust applied to substrate (100 or 400 mg/sq ft)
Pb Conc	Nominal lead concentration (HIGH or LOW)
Date	Date of the test
Time	Time of the test
Test No	Test number
Housevac	Vacuum cleaner (either A, B, C, or D)
Dust Size	Size of the dust
Dust Applied	Amount of dust applied
Bag Weight Change	Increase in the bag weight from vacuuming

The procedures generating the data in Table B-5 follow:

1) Use a new bag in each vacuum at the beginning of the day
2) Perform the tests according to the test sequence for the dust preconditioning
3) Deposit dust. Determine the actual weight of dust deposited
4) Grind-in if applicable
5) Determine tare weight of each bag before each use
6) Run free for 40 sec, cool 2 min, brush and record weight after 1 more min
7) Vacuum for 40 sec with the vacuum indicated in the test sequence for dust preconditioning
8) Record the time of the vacuuming
9) Reweigh the bag after 40 sec vac (cool 2 min, brush and record weight after 1 more min)
10) Repeat tare-vac-reweigh using the vacuum cleaner and particle size designated in test sequence, which utilizes the same substrate with the same dust loading and lead conc.
11) Vacuum the wand and brush on all vacuum cleaners after completing all tests on the substrate (no weighing)

Table B-5: Dust Preconditioning Data

Gravimetrics Data										
Substrate	Grind-in	Amount (mg/sq ft)	Pb Conc	Date	Time	Test No	Housevac	Dust Size (microns)	Dust Applied (g)	Bag Weight Change (g)
CRPT	NO	400	LOW	8/23/94	9:56	101	D	150-212	2.643	2.172
CRPT	NO	400	LOW	8/23/94	10:21	102	B	250-2000	2.743	2.451
CRPT	NO	400	LOW	8/23/94	10:53	103	B	53-106	2.678	2.115
CRPT	NO	400	LOW	8/23/94	11:27	104	C	106-150	2.796	2.063
CRPT	NO	400	LOW	8/23/94	11:51	105	A	212-250	2.737	3.104
CRPT	NO	400	LOW	8/23/94	12:12	106	C	<53	2.608	1.997
UPHOL	NO	400	LOW	8/23/94	12:30	107	A	106-150	2.752	2.705
UPHOL	NO	400	LOW	8/23/94	12:56	108	B	<53	2.611	2.291
UPHOL	NO	400	LOW	8/23/94	13:39	109	D	250-2000	2.860	2.636
UPHOL	NO	400	LOW	8/23/94	14:40	110	C	212-250	2.802	2.528
UPHOL	NO	400	LOW	8/23/94	15:15	111	A	150-212	2.661	2.640
UPHOL	NO	400	LOW	8/23/94	15:55	112	D	53-106	2.763	2.155
UPHOL	NO	100	HIGH	8/23/94	16:30	113	D	106-150	0.700	0.650
UPHOL	NO	100	HIGH	8/24/94	8:55	114	D	<53	0.590	0.419
UPHOL	NO	100	HIGH	8/24/94	9:11	115	A	150-212	0.743	0.748
UPHOL	NO	100	HIGH	8/24/94	9:30	116	B	212-250	0.720	0.769
UPHOL	NO	100	HIGH	8/24/94	9:47	117	C	53-106	0.696	0.587
UPHOL	NO	100	HIGH	8/24/94	10:07	118	C	250-2000	0.702	0.705
CRPT	NO	100	HIGH	8/24/94	10:41	119	C	150-212	0.723	0.332
CRPT	NO	100	HIGH	8/24/94	11:07	120	D	106-150	0.725	0.759
CRPT	NO	100	HIGH	8/24/94	11:25	121	A	53-106	0.663	0.656
CRPT	NO	100	HIGH	8/24/94	11:40	122	A	250-2000	0.659	0.659
CRPT	NO	100	HIGH	8/24/94	12:45	123	B	<53	0.628	0.739
CRPT	NO	100	HIGH	8/24/94	13:05	124	D	212-250	0.722	0.576
CRPT	YES	100	LOW	8/24/94	13:25	125	D	<53	0.660	0.477
CRPT	YES	100	LOW	8/24/94	13:46	126	B	106-150	0.667	0.514
CRPT	YES	100	LOW	8/24/94	14:11	127	A	250-2000	0.741	0.738
CRPT	YES	100	LOW	8/24/94	14:30	128	D	212-250	0.733	0.520
CRPT	YES	100	LOW	8/24/94	14:55	129	C	150-212	0.710	0.340
CRPT	YES	100	LOW	8/24/94	15:15	130	A	53-106	0.727	0.901
LINO	NO	400	LOW	8/24/94	15:35	131	B	106-150	2.783	2.545
LINO	NO	100	LOW	8/24/94	16:11	132	D	106-150	0.741	0.711
LINO	NO	100	HIGH	8/25/94	11:05	133	A	106-150	0.740	0.724
LINO	NO	400	HIGH	8/25/94	11:25	134	C	106-150	2.710	2.513
WOOD	NO	100	LOW	8/25/94	11:57	135	B	106-150	0.654	0.633
WOOD	NO	100	HIGH	8/25/94	12:20	136	C	106-150	0.737	0.678
CRPT	YES	400	HIGH	8/25/94	12:48	137	B	150-212	2.785	1.965
CRPT	YES	400	HIGH	8/25/94	13:45	138	A	106-150	2.937	2.105
CRPT	YES	400	HIGH	8/25/94	14:32	139	C	212-250	2.744	0.575
CRPT	YES	400	HIGH	8/25/94	14:53	140	D	53-106	2.807	2.828
CRPT	YES	400	HIGH	8/25/94	15:10	141	A	<53	2.730	2.833
CRPT	YES	400	HIGH	8/25/94	15:25	142	D	250-2000	2.901	1.871
TILE	NO	100	LOW	8/23/94	9:49	201	A	106-150	0.661	0.679
TILE	NO	400	HIGH	8/23/94	10:28	202	D	106-150	2.672	2.459
TILE	NO	400	LOW	8/23/94	11:02	203	C	106-150	2.868	2.953
TILE	NO	100	HIGH	8/23/94	11:35	204	B	106-150	0.711	0.618
WOOD	NO	400	LOW	8/23/94	12:05	205	D	106-150	2.705	2.502
WOOD	NO	400	HIGH	7/25/94	13:45	206	A	106-150	2.730	2.360
CRPT	NO	400	HIGH	8/23/94	14:10	207	B	212-250	2.729	1.565
CRPT	NO	400	HIGH	8/23/94	14:33	208	C	250-2000	1.904	1.353

Table B-5: Dust Preconditioning Data (continued)

Gravimetrics Data										
Substrate	Grind-in	Amount (mg/sq ft)	Pb Conc	Date	Time	Test No	Housevac	Dust Size (microns)	Dust Applied (g)	Bag Weight Change (g)
CRPT	NO	400	HIGH	8/23/94	14:55	209	C	53-106	2.698	2.021
CRPT	NO	400	HIGH	8/23/94	15:14	210	B	106-150	2.695	0.803
CRPT	NO	400	HIGH	8/23/94	15:35	211	D	<53	2.658	3.574
CRPT	NO	400	HIGH	8/23/94	15:57	212	A	150-212	2.718	3.145
CRPT	NO	100	LOW	8/23/94	16:17	213	C	212-250	0.685	0.439
CRPT	NO	100	LOW	8/24/94	8:35	214	A	106-150	0.699	0.762
CRPT	NO	100	LOW	8/24/94	8:54	215	D	53-106	0.642	0.527
CRPT	NO	100	LOW	8/24/94	9:10	216	D	250-2000	0.750	0.647
CRPT	NO	100	LOW	8/24/94	9:35	217	A	<53	0.605	0.455
CRPT	NO	100	LOW	8/24/94	9:53	218	B	150-212	0.677	0.583
CRPT	YES	400	LOW	8/24/94	10:25	219	D	106-150	2.736	2.019
CRPT	YES	400	LOW	8/24/94	10:43	220	A	<53	2.623	2.146
CRPT	YES	400	LOW	8/24/94	11:08	221	C	250-2000	2.708	1.731
CRPT	YES	400	LOW	8/24/94	11:26	222	B	150-212	2.720	2.155
CRPT	YES	400	LOW	8/24/94	11:41	223	C	53-106	2.727	1.895
CRPT	YES	400	LOW	8/24/94	12:33	224	B	212-250	2.750	2.605
UPHOL	NO	100	LOW	8/24/94	13:12	225	B	250-2000	0.700	0.638
UPHOL	NO	100	LOW	8/24/94	13:32	226	D	106-150	0.678	0.604
UPHOL	NO	100	LOW	8/24/94	13:40	227	D	150-212	0.688	0.575
UPHOL	NO	100	LOW	8/24/94	14:01	228	A	53-106	0.661	0.564
UPHOL	NO	100	LOW	8/24/94	14:25	229	A	212-250	0.700	0.699
UPHOL	NO	100	LOW	8/24/94	14:43	230	C	<53	0.643	0.362
CRPT	YES	100	HIGH	8/24/94	14:48	231	C	<53	0.613	0.336
CRPT	YES	100	HIGH	8/24/94	15:33	232	C	106-150	0.689	0.394
CRPT	YES	100	HIGH	8/24/94	15:53	233	B	53-106	0.684	0.721
CRPT	YES	100	HIGH	8/25/94	10:19	234	A	212-250	0.721	0.716
CRPT	YES	100	HIGH	8/25/94	11:05	235	D	150-212	0.678	0.539
CRPT	YES	100	HIGH	8/25/94	11:28	236	B	250-2000	0.690	0.561
UPHOL	NO	400	HIGH	8/25/94	12:46	237	D	212-250	2.756	2.640
UPHOL	NO	400	HIGH	8/25/94	13:00	238	B	106-150	2.778	2.582
UPHOL	NO	400	HIGH	8/25/94	14:15	239	A	250-2000	2.785	2.700
UPHOL	NO	400	HIGH	8/25/94	14:35	240	A	53-106	2.775	2.500
UPHOL	NO	400	HIGH	8/25/94	14:50	241	C	150-212	2.742	2.540
UPHOL	NO	400	HIGH	8/25/94	15:05	242	B	<53	2.620	1.834

APPENDIX C: SIEVED DUST DATA

The data in the following tables is derived from both the gravimetrics and lead analysis data. The two files were merged matching the lead analysis with the corresponding test data for sieved dust and the values for relevant variables are reported. Table C-1 consists of the sieved dust data. The description of the data in each column of Table C-1 is listed below:

Column Name	Description
Test	Sample test number
TestNos	SIx sample test numbers sieved together
Size	Size of the dust sampled
Date	Date of the sampling
Team	Team responsible for sampling
Dust Type	Type of dust (either from NEW or OLD home)
Dust Sample Weight	Amount of dust sent to lab for lead analysis
Run	Lead analysis run number
Preparation Batch	Lead analysis preparation batch number
Instrument Batch	Lead analysis instrument batch number
Lead Comment	Lead analysis comment number
Instrument Response	Lead analysis instrument response
Sample Weight	Weight of sample used in the lead analysis
PB	Lead amount estimated from analysis
Dust Lead Conc	Lead concentration estimated from analysis
Instrument	Type of instrument used in analysis (either ICP or GFAA)

Table C-1: Sieved Dust Data

Gravimetrics Data						
Test	TestNos	Size	Date	Operator	Dust Type	Dust Sample Weight
601	601-606	<53	8/17/93	MOORE	NEW	0.778
602	601-606	53-106	8/17/93	MOORE	NEW	0.709
603	601-606	106-150	8/17/93	MOORE	NEW	0.777
604	601-606	150-212	8/17/93	MOORE	NEW	0.783
605	601-606	212-250	8/17/93	MOORE	NEW	0.699
606	601-606	250-2000	8/17/93	MOORE	NEW	0.761
621	621-626	<53	8/18/93	MOORE	NEW	0.724
622	621-626	53-106	8/18/93	MOORE	NEW	0.739
623	621-626	106-150	8/18/93	MOORE	NEW	0.789
624	621-626	150-212	8/18/93	MOORE	NEW	0.788
625	621-626	212-250	8/18/93	MOORE	NEW	0.729
626	621-626	250-2000	8/18/93	MOORE	NEW	0.719
607	607-612	<53	8/19/93	MOORE	OLD	0.731
608	607-612	53-106	8/19/93	MOORE	OLD	0.722
609	607-612	106-150	8/19/93	MOORE	OLD	0.730
610	607-612	150-212	8/19/93	MOORE	OLD	0.735
611	607-612	212-250	8/19/93	MOORE	OLD	0.797
612	607-612	250-2000	8/19/93	MOORE	OLD	0.715
627	627-632	<53	8/19/93	MOORE	OLD	0.743
628	627-632	53-106	8/19/93	MOORE	OLD	0.740
629	627-632	106-150	8/19/93	MOORE	OLD	0.767
630	627-632	150-212	8/19/93	MOORE	OLD	0.749
631	627-632	212-250	8/19/93	MOORE	OLD	0.792
632	627-632	250-2000	8/19/93	MOORE	OLD	0.762
641	641-646	<53	8/27/93	chambers	NEW	0.639
642	641-646	53-106	8/27/93	chambers	NEW	0.497
643	641-646	106-150	8/27/93	chambers	NEW	0.688
652	647-652	250-2000	8/27/93	MOORE	OLD	0.734
647	647-652	<53	8/27/93	MOORE	OLD	0.520
648	647-652	53-106	8/27/93	MOORE	OLD	0.658
649	647-652	106-150	8/27/93	MOORE	OLD	0.692
644	641-646	150-212	8/27/93	chambers	NEW	0.655
645	641-646	212-250	8/27/93	chambers	NEW	0.643
646	641-646	250-2000	8/27/93	chambers	NEW	0.715
650	647-652	150-212	8/27/93	MOORE	OLD	0.680
651	647-652	212-250	8/27/93	MOORE	OLD	0.731
667	667-672	<53	9/3/93	MOORE	OLD	0.612
668	667-672	53-106	9/3/93	MOORE	OLD	0.774
661	661-666	<53	9/3/93	chambers	NEW	0.597
662	661-666	53-106	9/3/93	chambers	NEW	0.614
663	661-666	106-150	9/3/93	chambers	NEW	0.669
664	661-666	150-212	9/3/93	chambers	NEW	0.685
665	661-666	212-250	9/3/93	chambers	NEW	0.684
666	661-666	250-2000	9/3/93	chambers	NEW	0.685
669	667-672	106-150	9/3/93	MOORE	OLD	0.783
670	667-672	150-212	9/3/93	MOORE	OLD	0.740
671	667-672	212-250	9/3/93	MOORE	OLD	0.678
672	667-672	250-2000	9/3/93	MOORE	OLD	0.754
681	681-686	<53	9/10/93	MOORE	NEW	0.592
682	681-686	53-106	9/10/93	MOORE	NEW	0.624

Table C-1: Sieved Dust Data (continued)

Lead Concentration Data								
Run	Preparation Batch	Instrument Batch	Lead Comment	Instrument Response	Sample Weight	PB	Pb Conc Recover	Instrument
31	501	E08233B	NA	0.5822	0.778	72.77	93.540	ICP
32	501	E08233B	NA	0.6798	0.709	84.98	119.857	ICP
33	501	E08233B	NA	0.6919	0.777	34.60	44.524	ICP
34	501	E08233B	NA	1.0915	0.783	54.57	69.700	ICP
40	501	E08233B	NA	0.1626	0.699	20.33	29.081	ICP
41	501	E08233B	NA	0.3242	0.761	16.21	21.302	ICP
42	501	E08233B	NA	0.6156	0.724	76.95	106.290	ICP
43	501	E08233B	NA	0.7221	0.739	90.27	122.148	ICP
44	501	E08233B	NA	0.8501	0.789	42.50	53.871	ICP
45	501	E08233B	NA	0.5144	0.788	25.72	32.640	ICP
46	501	E08233B	NA	0.2273	0.729	28.41	38.976	ICP
47	501	E08233B	NA	0.0746	0.719	9.32	12.968	ICP
48	501	E08233B	NA	2.1829	0.731	272.86	373.273	ICP
49	501	E08233B	NA	2.5710	0.722	321.38	445.118	ICP
58	501	E08233B	NA	2.4238	0.730	302.98	415.034	ICP
59	501	E08233B	NA	2.5491	0.735	318.64	433.520	ICP
60	501	E08233B	NA	2.3702	0.797	296.28	371.738	ICP
61	501	E08233B	NA	2.0726	0.715	259.08	362.343	ICP
62	501	E08233B	NA	2.1683	0.743	271.04	364.788	ICP
63	501	E08233B	NA	2.6315	0.740	328.94	444.510	ICP
64	501	E08233B	NA	1.8484	0.767	231.05	301.239	ICP
65	501	E08233B	NA	2.4412	0.749	305.15	407.410	ICP
66	501	E08233B	NA	2.0525	0.792	256.56	323.943	ICP
67	501	E08233B	NA	6.8177	0.762	1704.43	2236.778	ICP
49	502	E09023B	NA	0.3102	0.639	38.78	60.681	ICP
58	502	E09023B	NA	1.2123	0.497	60.61	121.962	ICP
59	502	E09023B	NA	0.6068	0.688	30.34	44.096	ICP
61	502	E09023B	NA	1.8463	0.734	230.79	314.424	ICP
62	502	E09023B	NA	1.5606	0.520	195.08	375.144	ICP
63	502	E09023B	NA	2.4905	0.658	311.31	473.119	ICP
64	502	E09023B	NA	2.0689	0.692	258.61	373.717	ICP
65	502	E09023B	NA	0.4202	0.655	21.01	32.078	ICP
66	502	E09023B	NA	0.3527	0.643	17.63	27.422	ICP
67	502	E09023B	NA	0.2951	0.715	14.76	20.637	ICP
74	502	E09023B	NA	1.9442	0.680	243.02	357.390	ICP
75	502	E09023B	NA	2.7349	0.731	341.86	467.664	ICP
40	504	E11083A	NA	1.8708	0.612	233.85	382.108	ICP
41	504	E11083A	NA	2.8396	0.774	354.95	458.592	ICP
42	504	E11083A	NA	0.7168	0.597	71.68	120.074	ICP
43	504	E11083A	NA	0.7011	0.614	70.11	114.184	ICP
44	504	E11083A	NA	0.6026	0.669	30.13	45.035	ICP
45	504	E11083A	NA	0.6562	0.685	32.81	47.896	ICP
46	504	E11083A	NA	0.5564	0.684	27.82	40.675	ICP
47	504	E11083A	NA	0.2671	0.685	13.35	19.493	ICP
48	504	E11083A	NA	2.5937	0.783	324.21	414.064	ICP
49	504	E11083A	NA	6.3087	0.740	315.44	426.264	ICP
58	504	E11083A	NA	6.5902	0.678	329.51	486.003	ICP
59	504	E11083A	NA	6.8124	0.754	851.55	1129.377	ICP
125	505	E11083A	NA	0.6752	0.592	67.52	114.056	ICP
126	505	E11083A	NA	0.6791	0.624	84.88	136.030	ICP

Table C-1: Sieved Dust Data

Gravimetrics Data						
Test	TestNos	Size	Date	Operator	Dust Type	Dust Sample Weight
683	681-686	106-150	9/10/93	MOORE	NEW	0.690
684	681-686	150-212	9/10/93	MOORE	NEW	0.693
685	681-686	212-250	9/10/93	MOORE	NEW	0.698
686	681-686	250-2000	9/10/93	MOORE	NEW	0.690
687	687-692	<53	9/10/93	MOORE	OLD	0.612
688	687-692	53-106	9/10/93	MOORE	OLD	0.656
701	701-706	<53	9/16/93	chambers	NEW	0.552
702	701-706	53-106	9/16/93	chambers	NEW	0.593
703	701-706	106-150	9/16/93	chambers	NEW	0.667
704	701-706	150-212	9/16/93	chambers	NEW	0.686
705	701-706	212-250	9/16/93	chambers	NEW	0.651
712	707-712	250-2000	9/16/93	MOORE	OLD	0.724
706	701-706	250-2000	9/16/93	chambers	NEW	0.675
689	687-692	106-150	9/10/93	MOORE	OLD	0.677
690	687-692	150-212	9/10/93	MOORE	OLD	0.619
691	687-692	212-250	9/10/93	MOORE	OLD	0.691
692	687-692	250-2000	9/10/93	MOORE	OLD	0.662
707	707-712	<53	9/16/93	MOORE	OLD	0.560
708	707-712	53-106	9/16/93	MOORE	OLD	0.666
709	707-712	106-150	9/16/93	MOORE	OLD	0.675
710	707-712	150-212	9/16/93	MOORE	OLD	0.679
711	707-712	212-250	9/16/93	MOORE	OLD	0.682

Table C-1: Sieved Dust Data (continued)

Lead Concentration Data								
Run	Preparation Batch	Instrument Batch	Lead Comment	Instrument Response	Sample Weight	PB	Pb Conc Recover	Instrument
127	505	E11083A	NA	0.5109	0.690	25.55	37.025	ICP
128	505	E11083A	NA	0.3652	0.693	18.26	26.349	ICP
129	505	E11083A	NA	0.3397	0.698	16.99	24.335	ICP
130	505	E11083A	NA	0.2610	0.690	13.05	18.916	ICP
131	505	E11083A	NA	1.8299	0.612	228.74	373.754	ICP
132	505	E11083A	NA	2.3695	0.656	296.19	451.505	ICP
66	504	E11083A	NA	0.6500	0.552	65.00	117.754	ICP
67	504	E11083A	NA	0.9013	0.593	90.13	151.990	ICP
73	504	E11083A	NA	0.6470	0.667	32.35	48.501	ICP
74	504	E11083A	NA	0.4195	0.686	20.97	30.573	ICP
75	504	E11083A	2	0.3411	0.651	17.06	26.200	ICP
76	504	E11083A	NA	8.5532	0.724	1069.15	1476.727	ICP
77	504	E11083A	NA	0.8184	0.675	40.92	60.623	ICP
158	505	E11083A	NA	2.3901	0.677	298.76	441.304	ICP
159	505	E11083A	NA	6.0027	0.619	300.14	484.871	ICP
160	505	E11083A	NA	5.3871	0.691	269.36	389.805	ICP
161	505	E11083A	NA	11.6840	0.662	584.20	882.477	ICP
79	504	E11083A	NA	2.1064	0.560	210.64	376.143	ICP
80	504	E11083A	NA	2.5017	0.666	312.71	469.538	ICP
81	504	E11083A	NA	2.4269	0.675	303.36	449.426	ICP
82	504	E11083A	NA	5.3365	0.679	266.83	392.968	ICP
91	504	E11083A	NA	6.4787	0.682	323.94	474.978	ICP

Data Entry Sheet
for
Pretest and Weekly Analysis of Sieved Dust

Procedure
Collect sample of each dust size, from new homes, as follows:
- Take approximately 0.678 g from dust container
- Deposit dust through sieve, onto plastic sheet, to simulate depositing of dust on substrate
- Determine weight of dust deposited
- Transfer dust on plastic sheet into labeled and weighed sample bottle
- Determine weight of dust sample in sample bottle
- Repeat all the above for each particle size
- Using new data sheet, repeat all the above for dust from older homes

Test No. TESTNOS
Date DATE
Operator OPERATOR
Dust Type DUSTYPE
(old or new homes)

Dust Applied (gm) (Balance No. APPBAL)			Dust Sample (gm) (Balance No. SAMPBAL)			
Total Wt	Final Wt	Net Wt	Total Wt	Tare Wt	Net Wt	
		> 53 μm SIZE				
APPTOT	APPFIN	APPNET	SAMPTOT	SAMPFIN	SAMPNET	BARSAMP Bar Code Label
TEST						
		53-106 μm				
_____	_____	_____	_____	_____	_____	Bar Code Label
		106-150 μm				
_____	_____	_____	_____	_____	_____	Bar Code Label
		150-212 μm				
_____	_____	_____	_____	_____	_____	Bar Code Label
		212-250 μm				
_____	_____	_____	_____	_____	_____	Bar Code Label
		250-2000 μm				
_____	_____	_____	_____	_____	_____	Bar Code Label

Samples Relinquished by: _____ Reviewed by _____
Samples Received by: _____ Date _____
Date: _____

APPENDIX D: SAMPLER DATA

The data in the following tables is derived from both the gravimetrics and lead analysis data. The two files were merged matching the lead analysis with the corresponding test data for samplers and the values for relevant variables are reported. Table D-1 consists of the sieved dust data. The description of the data in each column of Table D-1 is listed below:

Column Name	Description
Test	Test number
Date	Date of the test
Team	Team responsible for performing the test
Sampler	Sampler used in the test (either BN, CAPS, WIPE, or BRM)
Substrate	Substrate used in the test
Grindin	Whether or not the dust was ground in to the substrate (applied only to carpet and upholstery)
Amount	Amount of dust applied (either 100 or 400 mg/sq ft)
Nom Dust Lead Conc	Lead concentration deposited (either HIGH or LOW)
Dust Size	Size of the dust particles deposited on the carpet
Square	Square of the substrate used in the test
Time	Time of the test
Initial Gain	Initial increase from vacuuming with no dust deposited
Dust Load 1	Amount of dust applied to the substrate
Sampler Collect	Increase in the cassette or sampler dust container weight during the test
Final Collect	Increase in the weight of the cassette or sampler dust container weight from the final vacuuming
Dust Comment	Gravimetrics comment number
Run	Lead analysis run number
Preparation Batch	Lead analysis preparation batch number
Instrument Batch	Lead analysis instrument batch number
Instrument Response	Lead analysis instrument response
Sample Weight	Weight of the sample analyzed
Lead Amount	Lead amount estimated from analysis
Q	Notifier (*) of whether the sample was below IDL
Dust Lead Conc	Lead concentration estimated from analysis
Lead Comment	Lead analysis comment number
Instrument	Instrument used in the analysis

Table D-1: Sampler Data

Gravimetrics Data													
Test	Date	Team	Sampler	Substrate	Grindin	Amount (mg/sq ft)	Nom Dust Lead Conc	Dust Size	Square	Time	Initial Gain (g)	Dust Load 1(g)	Sampler Collect (g)
4-1	9/10/93	2	WIPE	LINO	NO	400	LOW	212-250	1	10:24	0.014	0.406	.
3-1	9/10/93	1	HVS3	CRPT	NO	400	LOW	53-106	4	10:40	0.734	0.359	0.320
3-2	9/10/93	1	CAPS	UPHO	NO	100	HIGH	<53	2	11:30	0.011	0.081	0.046
3-3	9/10/93	1	BN	UPHO	NO	100	HIGH	<53	3	12:45	.	0.119	0.076
3-4	9/10/93	1	BN	UPHO	NO	100	HIGH	212-250	4	13:00	.	0.116	-0.001
4-2	9/10/93	2	WIPE	LINO	NO	400	LOW	<53	2	10:40	.	0.371	.
4-3	9/10/93	2	CAPS	CRPT	NO	100	HIGH	53-106	1	12:15	0.104	0.115	0.098
4-4	9/13/93	2	BN	CRPT	NO	400	HIGH	<53	3	8:48	1.404	0.380	0.195
4-5	9/13/93	2	HVS3	CRPT	NO	400	HIGH	212-250	4	9:08	.	0.404	0.358
4-6	9/13/93	2	CAPS	CRPT	YES	400	LOW	<53	1	10:13	0.493	0.421	0.272
4-7	9/13/93	2	HVS3	CRPT	YES	400	LOW	212-250	2	10:30	.	0.400	0.263
4-8	9/13/93	2	WIPE	LINO	NO	400	HIGH	106-150	4	11:21	0.017	0.411	.
3-6	9/13/93	1	HVS3	WOOD	NO	400	LOW	106-150	2	9:10	0.072	0.422	0.398
3-7	9/13/93	1	BN	WOOD	NO	400	LOW	53-106	3	9:45	.	0.404	0.352
3-8	9/13/93	1	HVS3	CRPT	NO	400	HIGH	150-212	1	10:10	0.093	0.433	0.306
3-9	9/13/93	1	BN	CRPT	NO	400	HIGH	250-2000	2	10:40	.	0.433	0.008
3-10	9/13/93	1	CAPS	CRPT	YES	400	HIGH	53-106	3	11:30	1.304	0.507	0.404
3-11	9/13/93	1	BN	CRPT	YES	400	LOW	150-212	1	13:15	0.065	0.418	-0.003
3-12	9/13/93	1	CAPS	WOOD	NO	400	HIGH	150-212	4	14:05	0.010	0.139	0.388
3-13	9/13/93	1	CAPS	LINO	NO	100	LOW	106-150	2	15:20	-0.008	0.113	0.098
3-14	9/14/93	1	BN	WOOD	NO	100	LOW	212-250	1	9:10	0.002	0.106	0.051
3-15	9/14/93	1	CAPS	WOOD	NO	100	LOW	<53	2	10:50	.	0.103	0.064
4-9	9/13/93	2	CAPS	UPHO	NO	100	LOW	53-106	4	13:20	0.046	0.098	0.066
4-10	9/13/93	2	HVS3	UPHO	NO	400	LOW	<53	1	14:15	0.022	0.433	0.329
4-11	9/13/93	2	CAPS	UPHO	NO	400	LOW	212-250	2	14:38	.	0.401	0.382
4-12	9/13/93	2	BN	CRPT	YES	100	LOW	53-106	1	15:39	0.055	0.110	0.013
4-13	9/13/93	2	HVS3	CRPT	YES	100	LOW	53-106	2	16:04	.	0.115	0.103
4-14	9/14/93	2	WIPE	WOOD	NO	100	LOW	150-212	2	8:45	0.014	0.096	.
4-15	9/14/93	2	HVS3	LINO	NO	100	HIGH	150-212	1	9:29	0.035	0.107	0.104
4-16	9/14/93	2	CAPS	CRPT	YES	100	HIGH	150-212	1	10:54	0.433	0.099	0.076
4-17	9/14/93	2	CAPS	LINO	NO	100	LOW	250-2000	2	12:45	0.007	0.119	0.108
4-18	9/14/93	2	HVS3	LINO	NO	100	LOW	53-106	3		.	0.085	0.081
4-19	9/14/93	2	CAPS	CRPT	NO	100	LOW	250-2000	1	14:28	0.295	0.115	0.121
4-20	9/14/93	2	BN	CRPT	NO	100	LOW	150-212	2	14:52	.	0.093	0.004
4-21	9/15/93	2	HVS3	WOOD	NO	400	HIGH	<53	2	8:44	0.035	0.392	0.335
4-22	9/15/93	2	CAPS	WOOD	NO	400	HIGH	212-250	3	9:21	.	0.399	0.371
3-16	9/14/93	1	HVS3	UPHO	NO	400	HIGH	53-106	3	11:10	0.016	0.408	0.360
3-17	9/14/93	1	BN	LINO	NO	400	HIGH	250-2000	1	13:10	-0.004	0.427	0.013
3-18	9/14/93	1	CAPS	LINO	NO	400	HIGH	53-106	2	15:00	.	0.427	0.346
3-19	9/15/93	1	BN	CRPT	YES	100	HIGH	212-250	2	9:20	0.045	0.097	-0.005
3-20	9/15/93	1	HVS3	CRPT	YES	100	HIGH	<53	3	9:45	.	0.110	0.096
3-21	9/15/93	1	BN	LINO	NO	100	HIGH	<53	3	10:30	-0.006	0.107	0.047
3-22	9/15/93	1	HVS3	LINO	NO	100	HIGH	212-250	4	11:05	.	0.124	0.095
3-23	9/15/93	1	BN	LINO	NO	400	LOW	150-212	4	13:00	0.000	0.420	0.206
3-24	9/15/93	1	WIPE	WOOD	NO	100	HIGH	250-2000	4	13:35	0.002	0.112	.
3-25	9/16/93	1	CAPS	WOOD	NO	400	HIGH	150-212	4	9:15	-0.006	0.389	0.369
4-23	9/15/93	2	HVS3	UPHO	NO	100	HIGH	150-212	3	10:20	0.042	0.108	0.135
4-24	9/15/93	2	WIPE	WOOD	NO	100	HIGH	53-106	2	11:10	0.069	0.100	.
4-25	9/15/93	2	BN	WOOD	NO	100	HIGH	106-150	3	12:05	.	0.107	0.046
4-26	9/15/93	2	HVS3	WOOD	NO	400	LOW	250-2000	2	12:40	0.005	0.421	0.388
4-27	9/15/93	2	CAPS	CRPT	NO	400	LOW	106-150	3	13:16	0.127	0.404	0.354
3-5	9/10/93	1	BN	UPHO	NO	400	LOW	150-212	3	16:30	-0.003	0.421	0.127

Table D-1: Sampler Data (continued)

Gravimetrics Data		Lead Concentration Data									
Final Collect (g)	Dust Comment	Run	Preparation Batch	Instrument Batch	Instrument Response (ug/mL)	Sample Weight (ug)	Lead Amount (ug)	Q	Dust Lead Conc (ug/g)	Lead Comment	Instrument
.	NA	92	507	E12023B	0.23360	.	23.358		.	NA	ICP
0.218	NA	61	506	E12023B	1.13130	0.320	56.57		176.766	NA	ICP
.	NA	62	506	E12023B	0.61650	0.046	15.41		335.033	NA	ICP
.	NA	23	508	V12073A	0.05156	0.076	25.78		339.211	NA	GFAA
0.123	NA	25	508	V12073A	0.04411	-0.001	1.1	*	.	NA	GFAA
0.039	NA	94	507	E12023B	0.40550	.	40.547		.	NA	ICP
0.069	NA	63	506	E12023B	1.54290	0.098	38.57		393.597	NA	ICP
.	NA	27	508	V12073A	0.02487	0.195	62.18		318.846	5	GFAA
0.672	NA	64	506	E12023B	5.70260	0.358	142.57		398.226	NA	ICP
.	NA	65	506	E12023B	0.70460	0.272	35.23		129.528	NA	ICP
0.386	NA	66	506	E12023B	0.28650	0.263	14.33		54.470	NA	ICP
0.024	NA	95	507	E12023B	1.51190	.	151.19		.	NA	ICP
.	NA	67	506	E12023B	0.33940	0.398	16.97		42.641	NA	ICP
0.016	NA	29	508	V12073A	0.03165	0.352	39.56		112.393	NA	GFAA
.	NA	73	506	E12023B	5.12140	0.306	128.04		418.415	NA	ICP
0.535	NA	31	508	V12073A	0.07298	0.008	1.82		228.063	NA	GFAA
0.717	NA	74	506	E12023B	3.86600	0.404	193.3		478.465	NA	ICP
0.345	NA	34	508	V12073A	0.01260	-0.003	0.32	*	.	NA	GFAA
0.015	7	75	506	E12023B	6.12420	0.388	153.11		394.601	NA	ICP
0.021	NA	76	506	E12023B	0.45870	0.098	11.47		117.013	NA	ICP
.	NA	35	508	V12073A	0.02710	0.051	0.68		13.284	NA	GFAA
0.042	NA	60	504	E11083A	0.30830	0.064	7.71		120.434	NA	ICP
0.03	NA	77	506	E12023B	0.40000	0.066	10		151.500	NA	ICP
.	8	133	505	E11083A	0.72820	0.329	36.41		110.673	NA	ICP
0.124	NA	139	505	E11083A	0.14320	0.382	7.16		18.741	NA	ICP
.	NA	38	508	V12073A	0.04474	0.013	1.12		86.038	NA	GFAA
0.087	NA	140	505	E11083A	0.52900	0.103	13.23		128.405	NA	ICP
0.013	NA	85	507	V12073A	0.04647	.	1.162		.	7	GFAA
-0.002	NA	141	505	E11083A	2.34540	0.104	58.64		563.798	NA	ICP
0.189	NA	142	505	E11083A	0.88130	0.076	22.03		289.885	NA	ICP
.	NA	74	505	V12073A	0.05411	0.108	1.35		12.525	6	GFAA
0	NA	144	505	E11083A	0.35760	0.081	8.94		110.380	NA	ICP
.	NA	145	505	E11083A	0.11310	0.121	2.83		23.357	NA	ICP
0.288	NA	39	508	V12073A	0.01157	0.004	0.29		72.313	NA	GFAA
.	NA	146	505	E11083A	2.52040	0.335	126.02		376.179	NA	ICP
0.03	NA	147	505	E11083A	2.91790	0.371	145.9		393.248	NA	ICP
0.004	NA	61	504	E11083A	3.30770	0.360	165.39		459.403	NA	ICP
.	NA	41	508	V12073A	0.06789	0.013	1.7		130.558	NA	GFAA
0.366	NA	62	504	E11083A	3.59200	0.346	179.6		519.075	NA	ICP
.	NA	42	508	V12073A	0.00536	-0.005	0.13	*	.	NA	GFAA
0.078	NA	63	504	E11083A	1.54170	0.096	38.54		401.484	NA	ICP
.	NA	50	508	V12073A	0.54739	0.047	13.68		291.165	NA	GFAA
0.051	NA	64	504	E11083A	1.49570	0.095	37.39		393.605	NA	ICP
0.183	NA	54	508	V12073A	0.27383	0.206	6.85		33.232	NA	GFAA
0.011	9	98	507	E12023B	0.10430	.	10.432		.	NA	ICP
0.005	NA	65	504	E11083A	4.96250	0.369	124.06		336.213	NA	ICP
0.033	10	148	505	E11083A	1.34810	0.135	33.7		249.648	NA	ICP
.	NA	99	507	E12023B	0.39520	.	39.524		.	NA	ICP
0.059	NA	61	508	V12073A	0.44710	0.046	11.18		242.989	NA	GFAA
0.013	NA	83	505	V12073A	0.18961	0.388	4.74		12.217	6	GFAA
0.114	NA	157	505	E11083A	0.46600	0.354	23.3		65.815	NA	ICP
0.282	NA	67	508	V12073A	0.16978	0.127	4.24		33.421	NA	GFAA

Data Entry Sheets
for
Sampler Tests

Test Sequence Number TEST
Date DATE
Operator OPERATOR

Test Identification

Sampler	SAMPLER	(Blue Nozzle, CAPS, HVS3 or WIPE)
Substrate	SUBSTRAT	(TILE, LINOleum, WOOD, UPHOlstery, CaRPeT)
Grind-in	GRINDIN	(Yes, No)
Dust Amount	AMOUNT	(100, 400 mg/ft^2)
Pb Conc	PBCONC	(Low, High)
Dust Size	SIZE	(>53, 53-106, 106-150, 150-212, 212-250, 250-2000)
Team	TEAM	(Number 1 or 2)
Square number	SQUARE	(1, 2, 3 or 4) 1=first, 3=last for carpet and upholstery, else 4=last)

Procedure

Perform the tests according to the sampler test sequence in Appendix Q, and procedures in Appendix E, F, G or H. Housevac A will be used to vacuum the first square before sampler tests, or to vacuum the last square after sampler tests.

If first square:
- Tare weigh bag (run free for 40 seconds, cool 2 minutes, brush and record weight after 1 more minute)
- Vac square for 40 seconds with Housevac A
- Reweigh bag (cool 2 minutes, brush and record weight after 1 more minute)

Deposit dust in specified square and weigh the amount deposited (Grind-in dust if applicable)
Sample dust according to the appropriate protocol, weigh the dust collected (except for wipes)
Prepare the dust sample for analysis
If last square:
- Tare weigh bag (run free for 120 seconds, cool 2 minutes, brush and record weight after 1 more minute)
- Vac square for 120 seconds with Housevac A
- Reweigh bag (cool 2 minutes, brush and record weight after 1 more minute)

Vacuum dust from wand and brush (no weighing)

	Weight of Dust (Balance # BALDUST)				Weight of Bag (Balance # BALBAG)	
	Total Wt. gm.	Final Wt. gm.	Net Wt. gm.	Time	Weight gm.	Increase gm.
Initial weight of bag (if first or last square)	.0				BAGWT	
Vacuum and reweigh bag (if first square)	.1				VACWTO	INCREASO
Dust deposited	.2 ADDTOT1	TARETOT1	NETADD1	TIME		
Dust collected by sampler (exclu wipes)	.3 TOTCOLL	TARECOLL	NETCOLL		FINTARE	
Vacuum & reweigh bag (if last square)	4.				FINBAG	FININC

BARSAMP	BARBLANK
Bar Code for Sample	Bar Code for Blank

NOTE: Submit one blank for each sampler, once each week

Sample relinquished by _____ Reviewed by _____
Sample received by _____ Date reviewed _____
Date of transfer _____

APPENDIX E: VACUUM CLEANER DATA

The data in the following tables is derived from both the gravimetrics and lead analysis data. The two files were merged matching the lead analysis with the corresponding test data for vacuum cleaners and the values for relevant variables are reported. Table E-1 consists of the sieved dust data. The description of the data in each column of Table E-1 is listed below:

Column Name	Description
Test	Test numbert
Date	Date of test
Team	Team responsible for test
Vac	Vacuum cleaner (either A, B, C, or D)
Substrate	Substrate used in the test
Grindin	Whether the dust was ground-in to the substrate (applies to carpet and upholstery substrates only)
Amount	Amount of dust applied (either 100 or 400 mg/sq ft)
Nom Dust Lead Conc	Lead concentration deposited (either HIGH or LOW)
Dust Size	Size of the dust applied
Time	Time of the test
Initial Gain	Initial increase from vacuuming with no dust deposited
Dust Load 1	Amount of first dust loading
Gain - Load 1	Increase from first vacuuming
Dust Load 2	Amount of second dust loading
Gain - Load 2	Increase from second vacuuming
Dust Load 3	Amount of third dust loading
Gain - Load 3	Increase from third vacuuming
No Dust - Gain 1	Increase from fourth vacuuming (no additional dust)
No Dust - Gain 2	Increase from fifth vacuuming (no additional dust)
No Dust - Gain 3	Increase from sixth vacuuming (no additional dust)
Dust Comnt	Gravimetrics comment number
Run	Lead analysis run number
Prep Batch	Lead analysis preparation batch number
Instr Batch	Lead analysis instrument batch number
Instr Resp	Lead analysis instrument response
Sample Wgt	Weight of sample used for lead analysis
Lead Amount	Lead amount estimated by analysis
Dust Lead Conc	Lead concentration estimated by analysis
Lead Comnt	Lead analysis comment number

(Note: Lead concentrations for all vacuum cleaner tests were performed using the ICP instrument)

Table E-1: Housevac Data

Gravimetrics Data															
Test	Date	Team	Vac	Substrate	Grindin	Amount	Pb Conc-Deposit	Dust Size (microns)	Time	Initial Gain	Dust Load 1 (g)	Gain - Load 1(g)	Dust Load 2 (g)	Gain - Load 2 (g)
1001	8/26/93	1	A	LINO	NO	400	HIGH	53-106	11:35	0.000	2.720	2.617	2.898	2.774
1002	8/26/93	1	D	LINO	NO	100	HIGH	<53	13:20	-0.020	0.600	0.425	0.639	0.510
1003	8/26/93	1	C	LINO	NO	100	HIGH	212-250	14:30	0.000	0.708	0.706	0.692	0.684
1004	8/26/93	1	B	LINO	NO	100	LOW	106-150	15:22	-0.001	0.688	0.668	0.698	0.670
1005	8/27/93	1	A	WOOD	NO	400	HIGH	150-212	9:50	0.128	2.735	2.712	2.747	2.715
1006	8/27/93	1	B	WOOD	NO	400	LOW	106-150	10:05	0.008	2.716	2.609	2.750	2.677
2001	8/26/93	2	C	TILE	NO	100	LOW	150-212	11:10	0.042	0.697	0.671	0.715	0.696
2002	8/26/93	2	B	TILE	NO	400	HIGH	212-250	13:20	0.001	2.871	2.780	2.727	2.653
2003	8/26/93	2	A	TILE	NO	100	LOW	150-212	14:15	0.087	0.697	0.590	0.747	0.726
2004	8/26/93	2	D	TILE	NO	400	HIGH	<53	15:20	0.067	2.717	2.005	2.761	1.889
2005	8/27/93	2	C	CRPT	NO	400	HIGH	212-250	9:01	0.153	2.801	1.452	2.732	1.486
2006	8/27/93	2	D	CRPT	NO	400	HIGH	<53	10:13	1.101	2.648	2.532	2.680	2.190
2007	8/27/93	2	A	CRPT	NO	400	HIGH	<53	11:19	0.232	2.630	2.343	2.703	2.200
1007	8/27/93	1	C	WOOD	NO	400	HIGH	150-212	11:05	0.045	2.710	2.551	2.756	2.652
2008	8/27/93	2	B	CRPT	NO	400	HIGH	212-250	15:05	0.043	2.778	1.650	2.672	1.895
2009	8/30/93	2	C	CRPT	YES	400	LOW	212-250	8:52	0.219	2.729	1.067	2.715	1.842
1008	8/27/93	1	D	WOOD	NO	100	LOW	<53	14:55	-0.024	0.542	0.510	0.673	0.577
1009	8/30/93	1	D	CRPT	NO	400	LOW	53-106	9:00	0.406	2.656	2.441	2.818	2.485
1010	8/30/93	1	A	CRPT	NO	400	LOW	53-106	10:05	0.081	2.833	2.615	2.741	2.564
2010	8/30/93	2	B	CRPT	YES	400	LOW	212-250	10:08	0.237	2.781	2.461	2.745	2.571
2011	8/30/93	2	D	CRPT	YES	400	LOW	<53	11:23	0.214	2.640	1.991	2.872	2.168
2012	8/30/93	2	A	CRPT	YES	400	LOW	<53	12:54	0.098	2.695	1.856	2.750	1.908
2013	8/30/93	2	A	LINO	NO	100	LOW	53-106	14:24	0.015	0.698	0.659	0.679	0.615
2014	8/30/93	2	B	LINO	NO	100	HIGH	150-212	15:15	0.008	0.734	0.694	0.702	0.681
1011	8/30/93	1	C	CRPT	NO	400	LOW	53-106	11:05	0.048	2.677	2.126	2.820	2.350
1012	8/30/93	1	B	CRPT	NO	400	LOW	53-106	12:45	0.230	2.645	2.493	2.736	2.534
1013	8/30/93	1	C	CRPT	NO	100	LOW	<53	14:00	0.071	0.515	0.460	0.684	0.436
1014	8/30/93	1	D	CRPT	NO	100	LOW	212-250	15:15	0.089	0.607	0.474	0.750	0.509
1020	9/1/93	1	B	UPHO	NO	100	HIGH	<53	8:30	0.056	0.674	0.505	0.730	0.591
2098	9/1/93	2	D	CRPT	YES	400	LOW	212-250	8:22	0.134	2.695	1.467	2.666	1.894
2099	9/1/93	2	C	CRPT	YES	400	LOW	<53	9:29	0.086	2.633	1.323	2.748	1.604
2033	9/1/93	2	C	LINO	NO	100	LOW	250-2000	10:52	0.129	0.705	0.597	0.680	0.665
2048	9/1/93	2	A	LINO	NO	400	LOW	<53	13:35	0.033	2.799	2.504	2.808	2.521
2061	9/1/93	2	D	LINO	NO	100	LOW	53-106	14:37	-0.026	0.692	0.646	0.696	0.611
2106	9/1/93	2	C	CRPT	NO	100	HIGH	53-106	15:34	0.077	0.684	0.488	0.697	0.513
2025	9/2/93	2	C	UPHO	NO	100	LOW	53-106	8:55	0.040	0.685	0.575	0.678	0.595
2065	9/2/93	2	C	WOOD	NO	400	HIGH	212-250	10:00	0.032	2.747	2.641	2.778	2.685
2068	9/2/93	2	A	WOOD	NO	100	HIGH	53-106	12:35	0.036	0.693	0.688	0.676	0.663
1085	9/1/93	1	C	UPHO	NO	100	HIGH	<53	9:30	0.084	0.727	0.545	0.702	0.607
1088	9/1/93	1	B	UPHO	NO	100	HIGH	212-250	10:45	0.035	0.792	0.795	0.743	0.739
1052	9/1/93	1	A	CRPT	YES	100	HIGH	212-250	13:30	0.216	0.693	0.681	0.761	0.859
1101	9/1/93	1	B	CRPT	YES	100	HIGH	212-250	14:30	0.034	0.774	0.385	0.671	0.497
1104	9/1/93	1	D	CRPT	YES	100	HIGH	<53	15:30	0.035	0.688	0.519	0.603	0.558
1030	9/2/93	1	D	UPHO	NO	400	HIGH	53-106	9:00	-0.013	2.887	2.633	2.910	2.676
1032	9/2/93	1	A	UPHO	NO	400	HIGH	53-106	10:00	0.023	2.913	2.791	2.937	2.843
1046	9/2/93	1	A	CRPT	NO	100	HIGH	106-150	11:00	0.212	0.724	0.680	0.665	0.671
1026	9/2/93	1	D	LINO	NO	100	HIGH	212-250	12:00	0.074	0.682	0.678	0.742	0.703
1027	9/3/93	1	C	LINO	NO	100	LOW	106-150	9:30	0.037	0.776	0.743	0.800	0.745
2095	9/2/93	2	D	WOOD	NO	400	HIGH	<53	11:00	-0.044	2.747	2.352	2.727	2.419

Table E-1: Housevac Data (continued)

Gravimetrics Data						Lead Concentration Data							
Dust Load 3 (g)	Gain - Load 3 (g)	No Dust- Gain 1 (g)	No Dust- Gain 2 (g)	No Dust- Gain 3 (g)	Dust Comnt	Run	Prep Batch	Instr Batch	Instr Resp (ug/mL)	Sample Wgt (g)	Lead Amount (ug)	Pb Conc-Recover (ug/g)	Lead Comnt
2.759	2.669	-0.009	-0.026	-0.020	NA	31	502	E09023B	2.6404	0.576	330.05	573.003	NA
0.669	0.457	-0.029	0.004	-0.005	NA	32	502	E09023B	1.6785	0.134	41.96	313.153	NA
0.671	0.664	0.001	-0.009	0.009	NA	33	502	E09023B	3.1479	0.482	157.40	326.546	NA
0.702	0.675	-0.007	0.009	-0.004	NA	34	502	E09023B	0.4322	0.386	21.61	55.986	NA
2.889	2.851	0.022	0.016	0.007	NA	40	502	E09023B	4.3170	1.195	539.63	451.569	NA
2.764	2.659	-0.008	-0.031	-0.013	NA	41	502	E09023B	0.5809	1.637	72.61	44.354	NA
0.679	0.637	0.012	0.021	0.001	NA	42	502	E09023B	0.4036	1.000	50.46	50.455	NA
2.753	2.690	0.007	-0.006	-0.014	NA	43	502	E09023B	3.6742	4.149	1837.10	442.781	1
0.680	0.680	-0.001	0.001	0.005	NA	44	502	E09023B	0.3010	1.198	37.62	31.404	NA
2.694	2.131	0.017	0.037	0.021	NA	45	502	E09023B	2.3356	3.224	1167.80	362.221	1
2.735	1.628	0.332	0.263	0.224	NA	46	502	E09023B	2.4423	1.329	610.57	459.424	NA
2.707	2.389	-0.053	0.022	0.030	NA	47	502	E09023B	2.1723	1.360	543.07	399.320	NA
2.722	2.230	0.100	0.062	0.040	NA	48	502	E09023B	3.0518	1.713	762.95	445.388	NA
2.739	2.542	0.061	-0.021	-0.009	NA	60	502	E09023B	2.9575	1.556	739.38	475.177	NA
2.707	2.249	0.541	0.351	0.276	NA	73	502	E09023B	3.0671	1.672	766.78	458.597	NA
2.712	1.556	0.590	0.392	0.331	NA	31	503	E11053A	0.3930	1.460	49.12	33.645	NA
0.716	0.528	0.000	-0.059	-0.012	1	76	502	E09023B	1.1783	0.231	29.46	127.522	NA
2.697	2.518	0.155	0.013	0.078	NA	32	503	E11053A	1.1763	0.378	58.82	155.595	NA
2.752	2.542	0.096	0.039	0.044	NA	33	503	E11053A	0.9297	0.772	116.21	150.528	NA
2.700	2.667	0.660	0.354	0.139	NA	34	503	E11053A	0.4234	1.902	105.85	55.652	NA
2.822	2.121	0.114	0.075	-0.003	NA	40	503	E11053A	0.6896	1.542	172.41	111.806	NA
2.720	1.978	0.116	0.076	0.069	NA	41	503	E11053A	0.9632	1.619	240.79	148.728	NA
0.699	0.651	0.002	0.010	-0.010	2	42	503	E11053A	1.9394	0.453	96.97	214.062	NA
0.710	0.662	-0.014	-0.001	-0.007	NA	43	503	E11053A	4.6537	0.548	232.68	424.608	NA
2.782	2.294	0.142	0.044	0.047	NA	44	503	E11053A	0.9883	0.946	123.53	130.584	NA
2.814	2.596	0.099	0.072	0.057	NA	45	503	E11053A	0.6321	0.535	79.01	147.680	NA
0.645	0.521	0.031	0.005	0.238	3	46	503	E11053A	0.5938	0.128	14.85	115.980	NA
0.684	0.684	0.104	-0.028	0.087	NA	47	503	E11053A	0.2385	0.518	29.81	57.553	NA
0.737	0.583	0.060	0.050	0.029	NA	48	503	E11053A	2.3475	0.159	58.69	369.104	NA
2.708	1.828	0.673	0.470	0.267	NA	49	503	E11053A	0.6899	1.362	86.23	63.313	NA
2.779	1.621	0.252	0.087	0.069	NA	58	503	E11053A	1.0456	1.139	130.70	114.750	NA
0.686	0.671	-0.001	0.001	0.002	NA	59	503	E11053A	0.1948	0.623	9.74	15.633	NA
2.962	2.680	0.019	0.015	-0.003	NA	60	503	E11053A	0.8788	1.743	219.71	126.050	NA
0.681	0.595	-0.005	-0.025	0.006	NA	61	503	E11053A	1.6534	0.540	82.67	153.093	NA
0.675	0.491	0.046	0.029	0.015	NA	62	503	E11053A	1.9281	0.576	241.01	418.424	NA
0.703	0.599	0.026	0.010	0.025	NA	63	503	E11053A	1.7470	0.409	87.35	213.570	NA
2.773	2.696	0.004	0.011	0.006	NA	64	503	E11053A	5.7564	1.680	719.55	428.304	NA
0.682	0.662	0.009	0.002	0.014	NA	65	503	E11053A	2.8758	0.622	359.47	577.934	NA
0.744	0.588	0.196	-0.126	0.074	NA	66	503	E11053A	1.5296	0.188	76.48	406.809	NA
0.651	0.668	0.015	0.026	-0.001	NA	67	503	E11053A	4.9871	0.978	623.39	637.411	NA
0.806	0.798	0.098	0.039	0.036	NA	73	503	E11053A	2.9894	0.981	373.67	380.912	NA
0.684	0.517	0.136	0.069	0.016	NA	74	503	E11053A	3.5664	0.446	178.32	399.821	NA
0.687	0.492	-0.106	0.120	0.012	NA	75	503	E11053A	3.6968	0.396	184.84	466.768	NA
2.775	2.528	0.119	0.008	0.013	NA	76	503	E11053A	3.0388	1.725	759.70	440.406	NA
2.702	2.596	0.054	0.031	0.023	NA	77	503	E11053A	3.3300	1.842	832.50	451.954	NA
0.703	0.662	0.052	0.081	0.016	NA	78	503	E11053A	4.2495	1.058	531.19	502.068	NA
0.685	0.504	0.099	0.035	0.056	NA	79	503	E11053A	3.8264	0.897	478.30	533.222	NA
0.759	0.723	0.015	0.007	0.001	NA	31	504	E11083A	3.2515	0.906	406.44	448.607	NA
2.751	2.541	0.067	0.018	-0.020	NA	80	503	E11053A	2.2853	1.615	571.32	353.762	NA

Table E-1: Housevac Data (continued)

Gravimetrics Data														
Test	Date	Team	Vac	Substrate	Grindin	Amount	Pb Conc-Deposit	Dust Size (microns)	Time	Initial Gain	Dust Load 1 (g)	Gain - Load 1(g)	Dust Load 2 (g)	Gain - Load 2 (g)
2109	9/2/93	2	A	CRPT	YES	100	HIGH	150-212	13:35	0.086	0.689	0.661	0.685	0.630
2112	9/2/93	2	C	CRPT	YES	100	HIGH	150-212	14:40	0.024	0.697	0.244	0.694	0.368
2018	9/3/93	2	B	WOOD	NO	100	HIGH	106-150	9:35	0.006	0.674	0.632	0.676	0.624
2020	9/3/93	2	A	WOOD	NO	100	LOW	150-212	10:48	0.138	0.692	0.685	0.685	0.666
1056	9/3/93	1	B	LINO	NO	400	LOW	150-212	10:30	0.014	2.649	2.559	2.980	2.900
1.31	9/3/93	1	A	CRPT	NO	100	LOW	<53	12:30	0.071	2.831	2.290	2.801	2.495
1.32	9/3/93	1	A	CRPT	NO	400	LOW	212-250	13:30	0.047	0.633	0.542	0.616	0.706
2052	9/3/93	2	D	WOOD	NO	400	LOW	250-2000	12:42	0.019	2.727	2.556	2.758	2.637
2064	9/3/93	2	A	LINO	NO	400	LOW	212-250	15:12	0.007	2.700	2.635	2.705	2.636
2085	9/7/93	2	D	LINO	NO	100	HIGH	150-212	12:11	-0.025	0.688	0.655	0.624	0.588
2088	9/7/93	2	A	LINO	NO	400	HIGH	106-150	13:08	0.008	2.771	2.686	2.744	2.637
2043	9/7/93	2	D	CRPT	YES	100	LOW	53-106	14:07	0.111	0.685	0.580	0.688	0.584
2044	9/7/93	2	B	CRPT	YES	100	LOW	53-106	15:10	0.000	0.694	0.523	0.682	0.521
2058	9/8/93	2	D	CRPT	NO	400	HIGH	212-250	11:57	0.189	2.804	1.874	2.685	1.809
1015	9/7/93	1	A	CRPT	NO	100	LOW	<53	9:40	0.111	0.704	0.560	0.655	0.532
1083	9/7/93	1	A	CRPT	NO	100	LOW	212-250	11:05	0.010	0.727	0.596	0.721	0.604
1069	9/7/93	1	C	CRPT	YES	400	HIGH	53-106	12:30	0.121	2.583	1.424	2.742	2.003
1075	9/7/93	1	B	LINO	NO	100	HIGH	<53	13:45	0.005	0.738	0.655	0.674	0.615
1076	9/7/93	1	C	LINO	NO	400	HIGH	53-106	15:15	0.021	2.700	2.482	2.608	2.420
1095	9/8/93	1	B	LINO	NO	400	HIGH	250-2000	10:00	0.003	2.818	2.768	2.725	2.689
1042	9/8/93	1	B	UPHO	NO	400	LOW	150-212	10:50	0.104	2.703	2.668	2.882	2.858
1044	9/8/93	1	A	UPHO	NO	400	LOW	150-212	12:45	0.027	2.846	2.760	2.853	2.812
1065	9/8/93	1	B	CRPT	NO	400	HIGH	250-2000	13:45	0.047	2.806	2.247	2.714	2.040
1119	9/8/93	1	D	CRPT	NO	400	HIGH	150-212	15:00	0.183	2.676	1.959	2.734	2.164
1038	9/9/93	1	B	CRPT	YES	400	LOW	150-212	8:30	0.417	2.636	2.019	2.707	2.315
2060	9/8/93	2	B	CRPT	NO	400	HIGH	<53	13:15	0.059	2.703	2.416	2.748	2.501
2089	9/8/93	2	D	UPHO	NO	400	LOW	<53	14:13	-0.042	2.684	2.099	2.706	2.145
2091	9/8/93	2	C	UPHO	NO	400	LOW	212-250	15:15	0.092	2.756	2.641	2.800	2.702
2101	9/9/93	2	A	UPHO	NO	400	LOW	212-250	8:28	0.027	2.764	2.711	2.740	2.694
2078	9/9/93	2	D	UPHO	NO	100	HIGH	150-212	9:40	-0.031	0.696	0.652	0.689	0.641
1079	9/9/93	1	B	WOOD	NO	100	LOW	212-250	9:40	0.008	0.664	0.600	0.657	0.642
1080	9/9/93	1	D	WOOD	NO	400	LOW	106-150	11:00	0.017	2.752	2.524	2.736	2.662
1111	9/9/93	1	A	WOOD	NO	100	HIGH	250-2000	13:00	0.021	0.794	0.781	0.730	0.730
1058	9/9/93	1	B	WOOD	NO	400	LOW	53-106	13:50	-0.006	2.466	2.269	2.755	2.525
1077	9/9/93	1	C	WOOD	NO	100	LOW	<53	15:00	0.033	0.864	0.756	0.713	0.653
2071	9/9/93	2	C	CRPT	NO	400	LOW	106-150	11:08	0.043	2.816	2.100	2.728	2.180
2022	9/9/93	2	B	CRPT	NO	100	LOW	150-212	12:45	0.023	0.670	0.481	0.682	0.528
2074	9/9/93	2	C	CRPT	NO	100	LOW	250-2000	13:51	0.043	0.716	0.505	0.716	0.461

Table E-1: Housevac Data (continued)

Gravimetrics Data						Lead Concentration Data							
Dust Load 3 (g)	Gain - Load 3 (g)	No Dust- Gain 1 (g)	No Dust- Gain 2 (g)	No Dust- Gain 3 (g)	Dust Comnt	Run	Prep Batch	Instr Batch	Instr Resp (ug/mL)	Sample Wgt (g)	Lead Amount (ug)	Pb Conc- Recover (ug/g)	Lead Comnt
0.683	0.640	0.071	0.000	0.009	NA	81	503	E11053A	3.8362	0.887	479.53	540.614	NA
0.693	0.372	0.108	0.080	0.043	NA	82	503	E11053A	3.0607	0.603	153.04	253.789	NA
0.679	0.646	0.003	-0.023	0.004	NA	91	503	E11053A	3.5074	0.517	175.37	339.207	NA
0.673	0.659	-0.003	0.005	-0.002	NA	92	503	E11053A	0.3705	0.543	18.52	34.115	NA
2.737	2.681	-0.058	-0.016	-0.016	NA	32	504	E11083A	0.3781	0.825	18.90	22.912	NA
2.957	2.605	0.098	0.053	-0.006	4	33	504	E11083A	1.0397	2.079	259.93	125.024	NA
0.788	0.388	0.126	0.044	0.055	5	34	504	E11083A	0.2526	0.975	25.26	25.907	NA
2.739	2.593	0.067	0.008	0.008	NA	93	503	E11053A	0.2814	1.805	35.17	19.485	NA
2.693	2.642	0.012	-0.006	-0.011	NA	94	503	E11053A	0.4255	1.415	53.18	37.585	NA
0.688	0.660	-0.027	-0.004	0.007	NA	31	506	E12023B	6.1292	0.625	306.46	490.336	NA
2.725	2.613	-0.009	-0.006	-0.039	NA	32	506	E12023B	5.2082	1.388	651.03	469.038	NA
0.684	0.562	0.017	-0.020	0.045	NA	33	506	E12023B	1.2641	0.470	63.21	134.479	NA
0.675	0.537	0.052	0.005	0.015	NA	34	506	E12023B	1.5475	0.421	77.38	183.789	NA
2.741	2.053	0.313	0.268	0.218	NA	100	505	E11083A	5.0513	1.552	631.41	406.838	NA
0.639	0.505	0.038	0.010	-0.003	NA	106	505	E11083A	0.8042	0.252	40.21	159.569	NA
0.716	0.628	0.099	0.040	0.023	NA	107	505	E11083A	0.2661	1.108	26.61	24.015	NA
2.758	1.949	0.470	0.186	0.110	NA	108	505	E11083A	3.3998	2.065	849.95	411.598	NA
0.713	0.674	0.010	-0.023	-0.007	NA	109	505	E11083A	1.5299	0.219	76.50	349.292	NA
2.761	2.604	0.011	-0.014	0.023	NA	110	505	E11083A	3.8394	1.987	959.85	483.065	NA
2.836	2.739	-0.018	-0.006	0.013	NA	111	505	E11083A	6.2411	2.087	1560.28	747.616	NA
2.687	2.660	0.056	0.043	0.043	6	112	505	E11083A	0.8920	1.801	111.50	61.911	NA
2.655	2.616	-0.001	0.041	-0.009	NA	113	505	E11083A	0.6304	1.440	78.80	54.719	NA
2.820	2.357	0.144	0.069	0.025	NA	40	506	E12023B	10.2920	1.543	2573.00	1667.531	NA
2.740	2.211	0.430	0.205	0.185	NA	41	506	E12023B	5.6419	1.912	705.24	368.848	NA
2.698	2.331	0.655	0.216	0.178	NA	42	506	E12023B	0.4604	1.664	57.55	34.587	NA
2.699	2.458	0.152	0.038	0.067	NA	114	505	E11083A	2.4624	1.397	615.60	440.659	NA
2.685	2.256	0.009	-0.036	0.012	NA	115	505	E11083A	0.6795	1.483	169.87	114.547	NA
2.685	2.596	0.061	0.030	0.040	NA	124	505	E11083A	0.5141	1.830	64.26	35.113	NA
2.799	2.710	0.008	0.018	0.035	NA	43	506	E12023B	0.5753	1.536	71.91	46.819	NA
0.679	0.638	0.048	-0.057	0.027	NA	44	506	E12023B	3.1784	0.954	397.30	416.457	NA
0.658	0.634	-0.005	0.001	-0.006	NA	45	506	E12023B	1.0438	0.815	130.48	160.092	NA
2.635	2.496	0.031	0.016	-0.008	NA	46	506	E12023B	0.6510	1.781	81.38	45.691	NA
0.717	0.718	0.004	0.021	0.002	NA	47	506	E12023B	10.6960	1.276	1337.00	1047.806	NA
2.770	2.640	0.012	0.027	0.014	NA	48	506	E12023B	1.7098	1.427	213.73	149.772	NA
0.710	0.628	0.002	0.017	0.002	NA	49	506	E12023B	0.7802	0.118	19.50	165.294	NA
2.738	2.185	0.203	0.085	0.103	NA	58	506	E12023B	0.3791	1.405	47.38	33.724	NA
0.675	0.564	0.068	0.043	0.033	NA	59	506	E12023B	0.2166	0.567	10.83	19.102	NA
0.688	0.513	0.032	0.018	0.008	NA	60	506	E12023B	0.1295	0.474	6.47	13.659	NA

Project 9802
WA No. 55

Data Entry Sheets
for
Housevac Tests

Test Sequence Number	TEST
Date	DATE
Operator	OPERATOR

Test Identification

Housevac	HOUSEVAC	**(A, B, C or D)**
Substrate	SUBSTRAT	**(TILE, LINOleum, WOOD, UPHOlstery, CaRPeT)**
Grind-in	GRINDIN	**(Yes, No)**
Dust Amount	AMOUNT	**(100, 400 mg/ft²**
Pb Conc	PBCONC#	**(Low, High)**
Dust Size	SIZE	**(<53, 53-106, 106-150, 150-212, 212-250, 250-2000)**
Team	TEAM	**(number 1 or 2)**

Procedure

Perform the tests according to the housevac test sequence in Appendix P, and vac procedure in Appendix I
Tare weigh new bag:
Run free 40 sec, cool 2 min, brush and record weight after 1 more min
Vacuum for 40 sec before any dust deposit
Reweigh bag (cool 2 min, brush and record weight after 1 more min)
Deposit dust, vacuum 40 sec, weigh the bag. Total of 3 times. (Grind-in after each dust deposit, if applicable)
Repeat vacuuming only (vacuum 40 sec, weigh the bag) 3 times
Shake dust from the bag, weigh, prepare for lead analysis
Vacuum dust from wand and brush (no weighing)

		Weight of Dust (Balance # BALDUST)				Weight of Bag (Balance # BALBAG)	
		Total Wt gm.	Tare Wt gm.	Net Wt gm.	Time	Weight gm.	Increase gm.
Tare weight of bag	.0					BAGWT	
Vacuum and weigh	.1				TIME	VACWT0	INCRES0
Add dust, vac & weigh	.2	ADDTOT1	TARETOT1	NETADD1		VACWT1	INCRES1
Add dust, vac & weigh	.3	ADDTOT2	TARETOT2	NETADD2		VACWT2	INCRES2
Add dust, vac & weigh	.4	ADDTOT3	TARETOT3	NETADD3		VACWT3	INCRES3
Vacuum & weigh	.5					VACWT4	INCRES4
Vacuum & weigh	.6					VACWT5	INCRES5
Vacuum & weigh	.7					VACWT6	INCRES6
Dust sent to lab	.8	LABTOT	LABTARE	LABNET			

BARSAMP	BARBLANK
Bar Code for Sample	Bar Code for Blank

Submit one blank for each week

Sample relinquished by _____
Sample received by _____
Date of transfer _____

Reviewed by _____
Date reviewed _____